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POUR L'EXPLORATION DE LA MER
CHARLOTTENLUND SLOT – DANEMARK

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IMPRIMERIE A/S L. IHRICH . COPENHAGEN

# High Accuracy Potentiometric Determination of the Chlorinity of Sea Water.

By

**Frede Hermann,**

Hydrografisk Laboratorium, Copenhagen.

THE usual Mohr-Knudsen method for chlorinity titration will generally give adequate accuracy when used on samples of water from small depths where salinity variations are great. In the examination of samples of water from greater depths by means of T-S diagrams and in dynamic calculations of currents, it will in many cases be desirable, however, to determine the salinity of the water with greater accuracy than that obtained by even the most thorough Mohr titration.

An accurate method of analysis of real practical importance should be a relatively rapid one, so that a large number of samples may be dealt with within a short time. When the task of finding such a method was commenced at this laboratory, the intention was to simplify the Volhardt method used here in connexion with the preparation of standard sea-water (1), a method yielding ample accuracy. It appeared, however, that the filtration and washing of the precipitate could not be carried out with sufficient speed, so the Volhardt titration was abandoned and replaced by the potentiometric method in which the time-wasting filtration is unnecessary.

Accurate potentiometric titrations of sea water have previously been performed by West and Robinson (2), and by Hindman, Anderson, and Moberg (3). The method described below is essentially the same as that used by the above-mentioned authors, but different electrodes are used, and the mechanical agitation and the weighing technique have been adapted so as to be more suitable for serial analyses.

Briefly, the procedure employed was as follows:—

By means of a Knudsen pipette 15 ml. were taken out of a number of sea-water samples and of one standard sea-water and introduced into weighing glasses with ground lids. The quantity measured was

accurately determined by weighing. Then, with mechanical agitation, strong silver nitrate solution (about 30 g.) was added by means of a burette until the excess of chloride ions was less than about 1 % of the amount originally present, and the quantity of silver nitrate added was accurately determined by weighing.

Finally, an accurate titration to the end-point was carried out volumetrically by means of a diluted silver nitrate solution of a concentration of one-tenth of the strong silver nitrate. The end-point was determined potentiometrically.

Between 16 and 20 analyses could be carried out in a day by a person accustomed to the routine.

The following is a detailed description of the apparatus and the procedure.

**Solutions.**

Strong silver nitrate. 5 litres 0·285 M silver nitrate solution were made up (30 g. equiv. to 15 g. of standard sea-water).

Diluted silver nitrate. 100 grammes of strong silver nitrate solution were diluted to 1 litre.

**Mechanical Agitation.**

As the quantities of fluid are to be determined by weighing, agitation must take place in closed glass vessels in order to prevent loss in weight by evaporation. Agitation was performed magnetically by means of an iron core, 25×8×3 millimetres, coated with a plastic and provided at the ends with inclined plexi-glass plates about 3 millimetres long. The iron core was slightly curved and placed with its convex surface towards the bottom of the glass so as to minimize friction. Close below the bottom of the glass a strong horseshoe magnet was placed, rotated by means of a motor at a rate of about 300 r.p.m. The field of the magnet caused the iron core to rotate so that the plexi-glass plates acted as a propeller which broke up the silver chloride and stirred it round in the liquid. The motor operated 6 magnets in series, so that liquid in six glasses could be agitated at a time.

**Measuring the Sea Water.**

The analyses were carried out in weighing glasses, 4·5 cm. × 6 cm., with ground lids. 9 glasses were used at a time, 1 for the standard sea-water (the lightest glass) and 8 for the water samples. The glasses were first weighed empty (with iron cores) and with the standard-water glass on the right-hand scale-pan as tare. Then 15 millilitres of the water samples and of the standard sea-water were pipetted by means of a Knudsen pipette into the glasses and the lids replaced immediately after filling. The glasses were then weighed again, with the standard sea-water glass as tare.

**Addition of Strong Silver Nitrate.**

Strong silver nitrate was now added from an ordinary burette, graduated in 1/10th millilitre (see Figure 1).

The burette was clamped to a metal tube free to turn on the stand so that the burette could easily be lifted and swung in over the glass which was placed on the plate above one of the magnets. The delivery tip of the burette was inserted through a rubber plate covering the glass, so that evaporation could be avoided almost entirely, and the tip was curved so that the silver nitrate fell on the side of the glass a little above the level of the liquid, thereby preventing splashing.

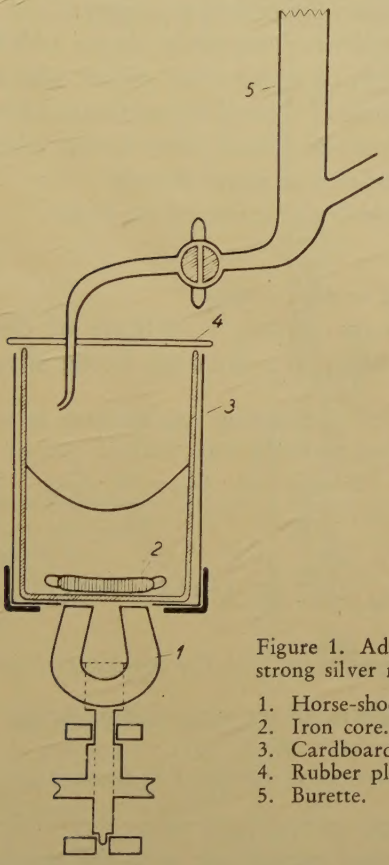


Figure 1. Addition of strong silver nitrate.

1. Horse-shoe magnet.
2. Iron core.
3. Cardboard sheet.
4. Rubber plate.
5. Burette.

The burette was placed over the glass as soon as possible after removal of the lid, the mechanical agitator was started, and the stop-cock opened. The salinity of the samples was assumed to be known approximately, and silver nitrate was added until the excess of chloride ions had been reduced to about 1 % of the original quantity.

After the addition of strong silver nitrate solution the agitator was stopped, the burette removed, and the lid placed on the glass as quickly as possible. The glass was then placed above one of the other magnets so that agitation was continued while silver nitrate was added to the

other glasses. During agitation, the glasses were protected from the light by cardboard sheets.

The glasses were now again weighed with the standard sea-water glass still on the right-hand scale-pan. Agitation was continued in the last four glasses while the first five glasses were weighed.

The following designations were used:—

| | |
|---|---|
| $H$ | weight of water sample. |
| $N$ | weight of standard sea-water. |
| $Ag_H$ | weight of strong silver nitrate added to H. |
| $Ag_N$ | weight of strong silver nitrate added to N. |
| $ag_H$ | volume of diluted silver nitrate added to H. |
| $ag_N$ | volume of diluted silver nitrate added to N. |
| $Cl_H$ | chlorinity of water sample. |
| $Cl_N$ | chlorinity of standard sea-water. |

Further:

$\Delta H = H - N$; $\Delta_1 Ag = Ag_H - Ag_N$

$\Delta ag = ag_H - ag_N$; $\Delta_2 Ag = f \cdot \Delta a_g$, 1 millilitre of diluted silver nitrate solution being equivalent to f grammes strong silver nitrate solution. f = about 0·1.

For the purpose of facilitating calculations in connexion with the analyses, the following formula was worked out:—

$$\frac{H \cdot Cl_H}{N \cdot Cl_N} = \frac{Ag_H + f \cdot ag_H}{Ag_N + f \cdot ag_N}; \quad \frac{H \cdot Cl_H - N \cdot Cl_N}{N \cdot Cl_N} = \frac{\Delta_1 Ag + \Delta_2 Ag}{Ag_N + f \cdot ag_N};$$

$$Cl_H - Cl_N = \frac{N}{H} \cdot \frac{Cl_N}{Ag_N + f \cdot ag_N} \left( \Delta_1 Ag + \Delta_2 Ag - \frac{Ag_N + f \cdot ag_N}{N} \Delta H \right),$$

$\frac{N}{H} \sim 1$ and $\frac{Ag_N + f \cdot ag_N}{N} \sim 2$ in the concentrations here used and $\Delta H$ always being relatively small we may with sufficient approximation put

$$Cl_H - Cl_N = \frac{Cl_N}{Ag_N + f \cdot ag_N} (\Delta_1 Ag + \Delta_2 Ag - 2\Delta H).$$

When weighing was carried out with the standard sea-water glass always on the right-hand scale-pan, values of $\Delta H$ and $\Delta_1 Ag$ were determined directly and weighing proceeded quickly as the same weights were always used in the weighing of the same glass. It is, however, necessary to have a modern, aperiodic beam-balance in order that weighing may be carried out sufficiently speedily.

### Potentiometric Titration with Diluted Silver Nitrate.

The indicator electrode used in the potentiometric titration was a wire of pure silver sealed in a glass tube and with its free end flattened

to form a plate of about 10×2 millimetres. The reference electrode was a wire of pure silver sealed in the burette outlet below the stop-cock. This placing of the electrode obviated the necessity of an extra reference electrode submerged in the liquid, and also avoided the drawbacks of the calomel electrode. The glass tube with the indicator electrode was fixed to the burette outlet. During titration, the point of the burette outlet must be submerged in the liquid so that the silver nitrate flowing from the burette is carried away from the indicator electrode by the rotation of the liquid (Figure 2).

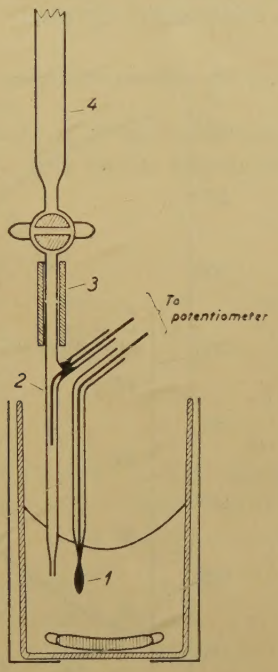


Figure 2.
Potentiometric titration
1. Indicator electrode.
2. Burette outlet with silver wire.
3. Rubber tubing.
4. Burette.

For measuring the electrode potential a pH-meter with milli-volt scale was used (Auto ionometer, type PHM, Radiometer, Copenhagen). On this apparatus the potential could be read continuously during the titration with an accuracy of 1 mV.

The diluted silver nitrate was measured by means of a burette of range 0—5 ml. and graduated in 2/100th ml., and the titration took place under mechanical stirring. The difference in potential between the electrodes may be given as $p = p_0 - k \cdot \log C$, in which C designates the concentration of silver ions in the titration liquid. As the relative variation of the concentration is at its maximum at the endpoint, the latter may be determined as the value of v at which $-\frac{dp}{dv}$ is at its maximum (v = the volume of diluted silver nitrate added). This method is rather cumbersome as it necessitates reading a series of corresponding values of p and v about the end-point and drawing a curve

for $-\frac{dp}{dv}$ against v. Figure 3 shows a specimen of such a curve. The potential at the end-point was determined by means of a series of such curves and proved in all cases to be at 180 mV. ± 3 mV. In the subsequent titrations dilute silver nitrate was added rapidly until the potential was about 230 mV. and then very carefully until a potential of 180 mV. was reached. As the mechanical agitation was very efficient the potentiometer registered almost instantaneously and titration to the end-point could be performed very quickly with an accuracy of about 0·01 ml. dilute silver nitrate.

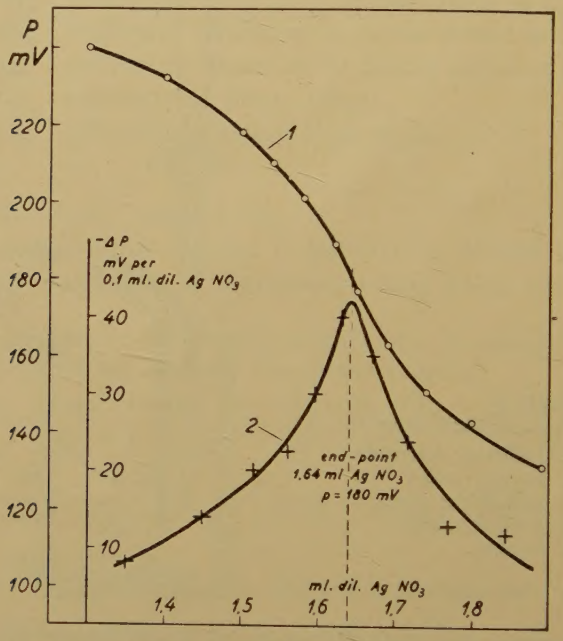


Figure 3. Titration curves.

1. Potential plotted agaist volume v of diluted silver nitrate.
2. $-\frac{\Delta p}{\Delta v}$ plotted against v.

The indicator electrode was quickly coated with a thin layer of silver chloride. To prevent this layer becoming too thick and the electrode too slow in adjustment, the electrode was rinsed in distilled water after each titration and wiped with filter paper once a day.

## Examination of the Accuracy of the Method.

Four sea-water samples of known concentrations were produced by dilution of about 150 ml. of standard sea-water with small quantities

of distilled water. The quantities of standard sea-water and of distilled water were determined by weighing. A duplicate analysis was carried out on each sample. The results are given in Table 1.

**Table 1.**

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Cl ‰ after weighing | $19{\cdot}268_0$ | $19{\cdot}282_7$ | $19{\cdot}315_5$ | $19{\cdot}348_0$ |
| Cl ‰ 1st titration | $19{\cdot}267_1$ | $19{\cdot}281_8$ | $19{\cdot}316_7$ | $19{\cdot}349_1$ |
| Cl ‰ 2nd titration | $19{\cdot}267_5$ | $19{\cdot}282_0$ | $19{\cdot}315_0$ | $1{\cdot}9348_6$ |

This high degree of conformity between results shows that the method is not subject to systematic error.

After this, double titrations were made of 19 sea-water samples from different depths in the Atlantic Ocean. The results appear in Table 2.

**Table 2.**

$(Cl_H - Cl_N) \cdot 10^3$

| Bottle No. | 838 | 840 | 841 | 843 | 845 | 847 | 848 |
|---|---|---|---|---|---|---|---|
| 1st titr. | 49·1 | 49·2 | 21·9 | 52·1 | 31·0 | 15·6 | —12·7 |
| 2nd titr. | 50·1 | 47·6 | 22·0 | 51·6 | 33·8 | 13·9 | —11·6 |
| 1st—2nd titr. | —1·0 | 1·6 | —0·1 | 0·5 | —2·8 | 1·7 | —1·1 |

| Bottle No. | 850 | 928*) | 929*) | 930 | 931 | 932 | 933 |
|---|---|---|---|---|---|---|---|
| 1st titr. | —37·8 | —32·7 | —38·7 | —43·4 | —45·9 | —49·8 | —29·9 |
| 2nd titr. | —37·9 | —29·7 | —36·1 | —43·0 | —45·2 | —48·8 | —28·2 |
| 1st—2nd titr. | 0·1 | —3·0 | —2·6 | —0·4 | —0·7 | —1·0 | —1·7 |

| Bottle No. | 934 | 935 | 936*) | 961 | 962 |
|---|---|---|---|---|---|
| 1st titr. | —23·8 | —22·6 | —65·5 | —25·6 | —38·6 |
| 2nd titr. | —26·9 | —22·9<br>—21·9 | —63·5 | —24·0 | —37·9 |
| 1st—2nd titr. | 3·1 | —0·2 | —1·9 | —1·6 | —0·7 |

From the deviations from the average a standard deviation $\sigma = 0{\cdot}8 \cdot 10^{-3}$ was calculated for all double titrations.

Between the first and second titration there is a systematic difference of $-0{\cdot}6 \cdot 10^{-3}$, which may be accounted for by the fact that the salinity increased by evaporation while the bottle was open.

In the case of the samples marked *) only very little water was left after the second titration. With these samples the influence of evaporation was also particularly great.

It is therefore advisable, especially with the standard water, not to use the last of the water, and to check the concentration of the old standard water when a new standard is put into use.

For the purpose of controlling the accuracy of the ordinary Mohr-Knudsen titration, 40 samples of water from the Atlantic Ocean were

titrated both by the potentiometric method and by the Mohr-Knudsen method. The average deviation was $5{\cdot}0 \cdot 10^{-3}$, and no systematic difference between the two methods was found.

Finally an example is given (Table 3) of the scheme used for recording the measurements in a series of analyses.

**Table 3.**

| Sample No. | | 1 | 2 | N | 3 | 4 |
|---|---|---|---|---|---|---|
| Glass No. | | 1—5 | 2—5 | 5 | 3—5 | 4—5 |
| Glass empty, | g. | 17·7019 | 7·1200 | 44·2794 | 8·3435 | 4·6125 |
| Glass + H, | g. | 17·6983 | 7·1165 | 59·5287 | 8·3417 | 4·6094 |
| Glass + H + Ag, | g. | 17·6634 | 7·0202 | 89·1607 | 8·2840 | 4·5773 |
| $\Delta$H, [N], | mg. | —3·6 | —3·5 | 15·2493 | —1·8 | —3·1 |
| $\Delta_1$Ag, [$Ag_N$], | mg. | —34·9 | —96·3 | 29·6320 | —57·7 | —32·1 |
| ag, | ml. | 3·57 | 4·39 | 5·005 | $4{\cdot}57_5$ | 4·79 |
| $\Delta$ag, | ml. | $-1{\cdot}43_5$ | $-0{\cdot}61_5$ | | —0·43 | $-0{\cdot}21_5$ |
| $\Delta_2$Ag, [f·$ag_N$], | mg. | —147·9 | —63·4 | 0·517 | —44·3 | —22·2 |
| $\Delta_1$Ag + $\Delta_2$Ag — 2$\Delta$H, | mg. | —175·6 | —152·7 | | —98·4 | —48·1 |
| $(Cl_H - Cl_N) \cdot 10^3$ | | —112·9 | —98·2 | | —63·3 | —30·9 |

Letters in square brackets refer to column N.

$Cl_N = 19{\cdot}380\ ‰$.

Standardization of diluted $AgNO_3$ against N:

$6{\cdot}02_5$ ml. dil. $AgNO_3 \sim 0{\cdot}3140$ g. N.

1 ml. dil. $AgNO_3 \sim 52{\cdot}12$ mg. N $\sim 0{\cdot}1032$ g. strong $AgNO_3$; $f = 0{\cdot}103_2$.

$$Cl_H - Cl_N = \frac{Cl_N}{Ag_N + f \cdot ag_N} (\Delta_1 Ag + \Delta_2 Ag - 2\Delta H)$$

$$\frac{19{\cdot}380}{30{\cdot}149} (\Delta_1 Ag + \Delta_2 Ag - 2\Delta H).$$

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1. Jacobsen, J. P., and Martin Knudsen. "Urnormal 1937 or primary standard sea-water 1937." Publ. Sci. Assoc. Ocean. Phys., **7**, 1940.
2. West, L. E., and R. J. Robinson. "Potentiometric analysis of sea-water. I. Determination of chlorinity." J. Mar. Res., **4** (1), p. 1, 1941.
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# On the Diurnal Migration of Zooplankton in Relation to the Discontinuity Layer.

By

**Kristian Vagn Hansen.**

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As a preliminary link in the investigation of the vertical distribution of zooplankton, Prof. J. T. Ruud, of Oslo, made a series of collections in the inner part of Oslo fjord, over a complete 24-hour cycle, during the period 26.—28. June 1947. His object was to test the usefulness of his method (a combination of bathythermograph and Clarke-Bumpus plankton sampler), and he also wished to find out what importance the discontinuity layer had as a limiting factor for the vertical distribution and migration of the separate species. I am greatly indebted to Prof. Ruud for permission to use this material.

The earlier investigations on the vertical migrations of the zooplankton — after evidence for this had been obtained — were directed especially to their causes, and showed the movements to be due to changes in the intensity of light, though hydrographical factors such as temperature, salinity, oxygen content, etc. may act as limiting factors in the distribution and migration of the separate species (e.g., Bogorov 1946, Clarke 1930, 1932, 1933, Hardy 1947, Kikuchi 1930, Nicholls 1933, Russell 1927 to 1934). The discontinuity layer, with its great variations in the hydrographical factors mentioned, may be the limit of the vertical distribution of the different species and their migrations. In the Sound the discontinuity layer forms an insurmountable barrier for the larvae of bottom-living animals: if they pass this, they die (Thorson 1946). According to the biological character and the sensitivity of the separate species there are 4 possibilities:—

1. Migration from the discontinuity layer to the surface.
2. Occurrence only in the discontinuity layer.
3. Migration from deep water (or bottom) to the discontinuity layer.
4. Migration from deep water (or bottom) up to the surface.

For evidence of these points we require:—

I. A method by which we can immediately determine the depth at which the discontinuity layer lies.

II. Plankton nets towed horizontally, which can indicate the volume of water flowing through the net; and from this volume can be derived the number of species per unit of volume.

In the present investigation the bathythermograph was used for the first purpose, and the Clarke-Bumpus plankton sampler for the second.

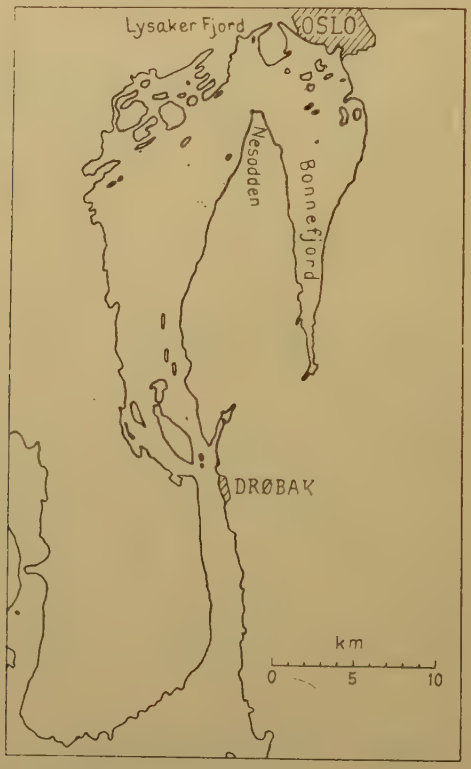


Figure 1.

**Topography and Hydrography.**

Two different localities in Oslo fjord were chosen for the collections — Bonnefjord on 24.—27. June and west of Nesodden on 28. June (Figure 1).

Bonnefjord is the innermost basin of Oslo fjord. The depth at the threshold in Drøbak Sound is 40 m., beyond which the hydrographical conditions are constant in the layers below 40 m. with a temperature of 6°—7°C. and a salinity of about 33 ‰. Furthermore, the oxygen content decreases with increasing depth so that in the deepest parts (below 150 m.) the oxygen content is very low. At several localities it

is nil. The surface layers on the other hand are subject to great hydrographical change (see B r a a r u d & R u u d 1937). The only station at which corresponding observations of temperature and salinity were made was in Bonnefjord on 24. June from 1300 to 1415 hrs.

Figure 2 shows the normal conditions at the locality and season in question. These are characterized by a high surface temperature (19°—20°C.), a marked discontinuity layer at about 10 m., with a temperature fall of about 10°C., and a constant temperature in deep water of about 6·8°C. The salinity in the discontinuity layer rises from about 20 to 31 ‰.

In Bonnefjord on 26. June at 1710, 2300 and 2330 hrs., and on 27. June at 0800 hrs., the temperature was recorded with the bathythermograph down to a depth of about 50 m., as shown in Figure 3.

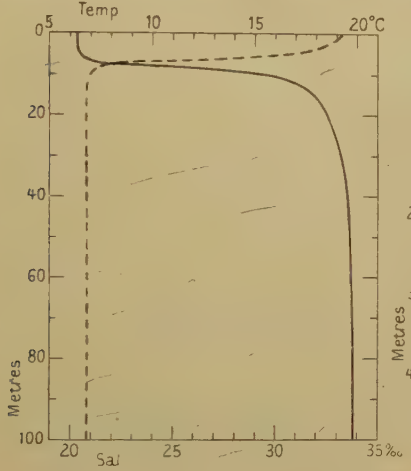


Figure 2. Distribution of temperature and salinity on 24. June from 1300 to 1415 hrs.

Figure 3. Temperature in Bonnefjord on 26. June at 2330 hrs.

The depth at which the net collections were made are indicated by a stroke. The uppermost depth was always 4 m., the intermediate depth was in the discontinuity layer (at 1800 hrs., 9 m.; at 2400 and 0830 hrs., 10·65 m.; and at Nesodden at 1300 hrs., 13 m.), and the lowest depth was 25 m. The surface temperature fell in the course of the night from 18·1° at 1700 hrs. to 14·7° at 0800 hrs.; with increasing depth, the temperature difference was evened out.

The discontinuity layer at 1710 hrs. was at approximately 9 m., with a very rapid temperature fall of 9·2°C. between 8·50 m. and 9·50 m., but later became somewhat deeper, with a less sharp temperature fall (at 1 m., ca. 3°C.; at 2·5 m., ca. 8°C.). At 25 m. the temperature varied between 6·3° and 6·1°C. This shows that an organism which breaks through the discontinuity layer is exposed to a temperature change of about 10°C. and a salinity change of 8—9 ‰ with a correspondingly great variation in oxygen content.

**Extract from the Log Book.**

| Date and Hour | | Locality | Weather | Depth of discontinuity layer |
|---|---|---|---|---|
| June | hrs. | | | |
| 26. | 1710 | Bonnefjord | — | 9 m. |
| 26. | 2330 | „ | cloudy, slight breeze. | 10·65 m. |
| 27. | 0800 | „ | cloudy; slight fog; calm, slight breeze. | 10·65 m. |
| 27. | 1000 | „ | calm, sunny. | 10·65 m. |
| 27. | 1030 | „ | calm, sunny. | 10·65 m. |
| 28. | 1300 | W. of Nesodden | slight breeze, sunny. | 13 m. |

The depth of the discontinuity layer was determined by means of the bathythermograph. To obtain as accurate a picture as possible of the population above, within, and below the discontinuity layer in a particular hydrographical situation, three plankton samplers were attached to the same wire in the depth mentioned. At the end of the wire was hung a 30 Kg. lead weight. With the exception of the sampler used at 25 m. at 1800 hrs., which failed to close and was at once used again, all the samplers worked satisfactorily, opening and shutting in series. Complete stations were made on 26. June at 1800 and 2400 hrs., and on 27. June at 0830 hrs. (over, within, and below discontinuity layer). At 1000 hrs. two samplers were lowered to 10·65 m. at a horizontal distance apart of 3 m. for 10 minutes. It was hoped to see in this way whether the population was quantitatively different at different places, whether the plankton occurred in clumps.

The nets used in the samplers were of No. 8 silk; the volume of water which passed through the samplers during the ten minutes varied between 3,700 and 6,300 litres.

**Enumeration.**

All Chaetognatha, *Meganyctiphanes norvegica*, and Hydromedusae were counted. Of the other species from one-tenth to one-hundredth part was counted, the samples being fractioned by means of L e a' s plankton divider. The total number was adjusted to the number of animals per thousand litres. Unless otherwise stated, the quantities given correspond to this unit of volume.

**Sources of Error.**

Various errors arise during the collection of the samples so that this method is not quantitatively exact, but the results are nevertheless comparable. Clogging of the meshes may occur, e.g., in areas with great abundance of plankton or in the presence of many *Cyanea capillata*. With the width of mesh in No. 8 silk (0·17—0·12 mm. when wet) a number of small organisms are able to pass through the net, e.g., copepodite stages of *Oithona helgolandica* and all stages of *Oithona nana*. The number of these in the samples is hardly therefore representative.

## The Distribution and Migration of the Various Species.

**1. Species occurring chiefly in the warm surface water with the discontinuity layer as the principal boundary.**

*Calanus finmarchicus* (Gunnerus), females. At 4 m. fewer than 10 individuals were taken at all the day stations; at 2400 hrs., however, over 1000 individuals were taken. At 25 m. numbers were fairly constant, but rose to a maximum at 0830 hrs. The same was found for the whole population of *Calanus finmarchicus*.

| Number/1000 litres, 25 m. | at 1800 hrs. | at 2400 hrs. | at 0830 hrs. |
|---|---|---|---|
| Females | 27 | 47 | 122 |
| Total *C. finmarchicus* | 98 | 143 | 303 |

During the day most individuals were found round about the discontinuity layer; their numbers decreased most rapidly the deeper the water. The upper limit for their migrations during the night probably lay between the surface and 4 m. (Fig. 4).

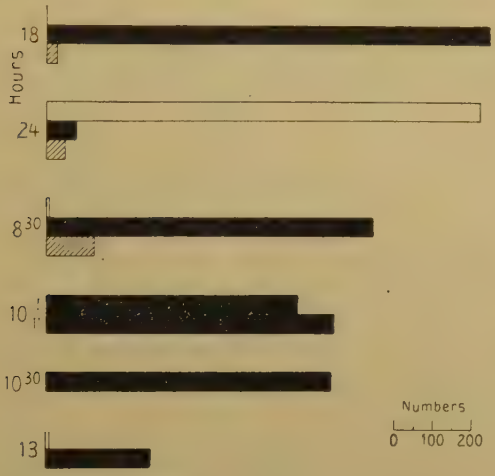


Figure 4. Number of *Calanus finmarchicus* females per 1000 litres at 4 metres (white column), in the discontinuity layer (black column), and at 25 metres (shaded column).

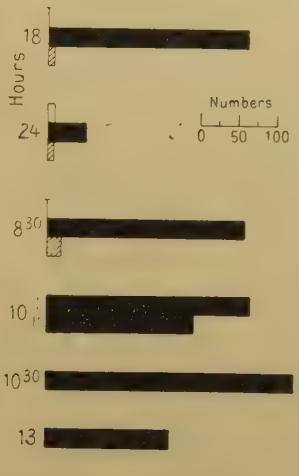


Figure 5. Number of *Calanus finmarchicus* males per 1000 litres; for signs and explanation see Figure 4.

*Centropages hamatus* (Lilljeborg). In the daytime this species was found around and within the discontinuity layer in large numbers. It disappeared from there at night, the maximal occurrence being in the neighbourhood of the surface. None was observed at 25 m. at any time. The adults approached nearer to the surface than the copepodite stages.

*Oithona nana* (Giesbrecht). Both adults and copepodites were between surface and discontinuity layer during the whole 24 hours. During the night there was a particularly large accumulation in the uppermost layers. The small population below the discontinuity layer did not seem to undergo any diurnal variation.

*Podon* spp. Only *Podon polyphemoides* (Leuckart) was determined, but *Podon leuckarti* (G. O. Sars) and *Podon intermedius* (Lilljeborg) are said to occur in the neighbourhood of Oslo (W i b o r g 1940). They are surface forms which migrate into the uppermost layers during the night, and are found at 25 m. in the daytime.

*Evadne nordmanni* (Lovén). This species is even more closely confined to the surface than *Podon*. It was not found at 25 m. Only a few were found during the day in the discontinuity layer.

**2. Species occurring in or close to the discontinuity layer.**

*Calanus finmarchicus*, males (Fig. 5). The day samples at 4 m. gave few or no specimens, and only 9 at 2400 hrs. In all samples at 25 m. the number was small but constant. In this locality the males seemed to be closely confined to the levels in and around the discontinuity layer. They migrate neither so near the surface (they probably stop between 4 m. and the discontinuity layer) nor so deep as the females. Earlier observations have shown that the males live at somewhat greater depths than the females (R u u d 1929, R u s s e l l 1934, W i b o r g 1940).

*Temora longicornis* (Fig. 6). For the females the upper boundary during the night lay between the surface and the discontinuity layer. The males were observed only in the discontinuity layer, and in greatly varying numbers. The females were more numerous than the males except at 1800 hrs. and 1300 hrs. The distribution of the copepodites resembled that of the males. In all samples they were fewer than the adults.

*Oithona helgolandica* (Claus), adults. During the day the maximum occurrence was in the discontinuity layer, but the number diminished greatly during the night. As the numbers at 4 m. were constant throughout the 24 hours, their upper boundary lay between 4 m. and the discontinuity layer. The copepodites were less mobile than the adults. The numbers at 25 m. were constant.

*Sarsia tubulosa* (M. Sars). In Danish waters in the summer of 1911 the highest temperatures at which *Sarsia tubulosa* was common were 9·4°C.—10·8°C. (0—8 m. in the Kattegat on 30. June) according to K r a m p 1927.

Bonnefjord; 26.—27. June 1947.

| Time | Discontinuity layer Depth (m.) | t°C. | Time | Clarke-Bumpus sampler Depth (m.) | t°C. |
|---|---|---|---|---|---|
| 1710 hrs. | 8—10 | 19—8 | 1725—1735 hrs. | 9 | 12·5—15 |
| 2300 hrs. | 9—14 | 19—7 | — | — | — |
| 2330 hrs. | 9—13 | 19—7 | 2348—2358 hrs. | 10·65 | 14—15 |
| 0800 hrs. | 9—13 | 19—8 | 0820—0830 hrs. | 10·65 | 11·5—12·5 |

At these stations in Bonnefjord *Sarsia tubulosa* occurs only in the discontinuity layer. The figures given below give the total number of *Sarsia tubulosa* in the whole volume of water which passed through the samplers.

| | | | | | at Nesodden |
|---|---|---|---|---|---|
| Time | 1800 hrs. | 2400 hrs. | 0830 hrs. | 1000 hrs. | 1300 hrs. |
| Number | 16 | 7 | 4 | 4 | 15 |

The distribution of *Sarsia tubulosa* seems to be determined essentially by temperature, the maximum temperature tolerable in the summer being about 15°C. In order to remain in the optimal temperature area of the hydrographical situation described *S. tubulosa* has sought to keep within the discontinuity layer the whole time. K r a m p (1915) connects the distribution with salinity. He writes, "*Sarsia tubulosa*, most abundant in the deeper strata ... The variations from day to day of the number of individuals are very large. A connexion between these variations and the hydrographical conditions is slightly indicated, as far as a higher salinity in the lower or the intermediate water-layers seems frequently to be followed by a greater number of *Sarsia*".

A closer investigation will probably show that both temperature and salinity act as limiting factors in the distribution of *Sarsia tubulosa*.

**3. Species found under the discontinuity layer and having this layer as the principal upper boundary.**

*Pseudocalanus minutus* (Krøyer). All stages occur in the greatest numbers from 0 to 50 m. in Bonnefjord (W i b o r g 1940). In the daytime none was found at 4 m. At night for the females the principal boundary lay in the uppermost part of the discontinuity layer, whilst by far the most males were found at 25 m. and did not migrate into the discontinuity layer.

*Oncaea borealis* (G. O. Sars), Syn. *O. conifera* (Sars) (not Giesbrecht). Earlier investigations in Bonnefjord have shown that this species occurs most abundantly from 0 to 50 m. (W i b o r g 1940).

The principal concentration of females during the daytime lay below the discontinuity layer at 25 m. (50 m.?). During the night they migrated towards the discontinuity layer. The males and copepodites were not found at all at 4 m. nor in the discontinuity layer. They live in somewhat deeper water than the females.

*Meganyctiphanes norvegica.* With the exception of three adults which were found at 2400 hrs. at 25 m. (all that occurred in the sample), the following figures refer to the larval stages. All specimens were counted.

Bonnefjord; 26.—27. June 1947. Number per 1000 litres.

| Depth | 1800 hrs. | 2400 hrs. | 0830 hrs. |
|---|---|---|---|
| 4 m. | 1 | 0 | 0 |
| Discontinuity layer | 42 | 545 | 3 |
| 25 m. | 33 | 1 (adult) | 8 |

Larval stages were found in the daytime right up to the discontinuity layer and they accumulated densely here during the night. They were not found at night at 25 m. Adults lived in the daytime below 25 m.;

at night the absolute upper boundary for these was in the lowest part of the discontinuity layer.

Chaetognatha: *Sagitta* spp. Only *Sagitta elegans* (Verrill) was determined, but according to Wiborg (1940) *S. setosa* (J. Müller) also occurs in Oslo fjord. Formerly *S. elegans* and *S. setosa* were known by the same name, *S. bipunctata* (Quoy and Gaimard), this name now being used for a form that lives in warmer zones. *Sagitta elegans* lives mostly in waters of a fairly low salinity and temperature. In their downward migration they are accordingly stopped by high salinity, and in their

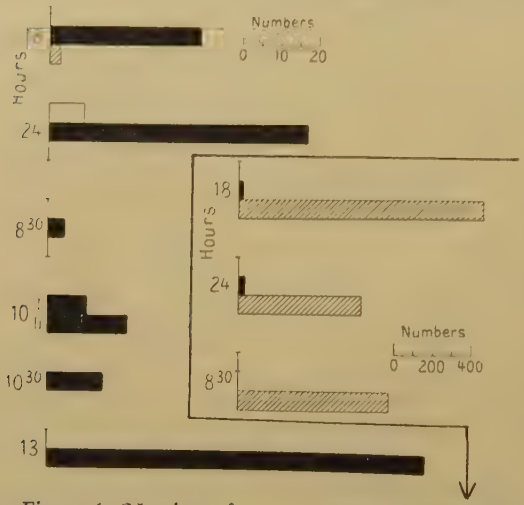


Figure 6. Number of *Temora longicornis* females per 1000 litres.




Figure 7. Number of *Oncaea borealis* females per 1000 litres.

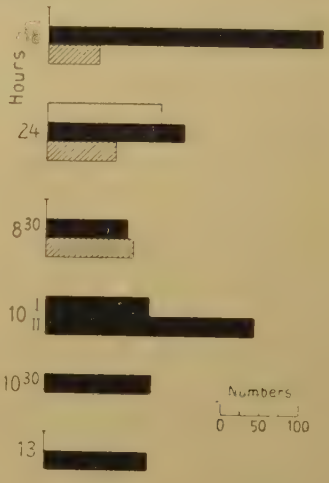


Figure 8. Number of *Calanus finmarchicus* copepodite stage V per 1000 litres.

For signs and explanation see Figure 4.

upward travel towards the surface by higher temperatures. The younger stages, however, live in the warm surface water and are able to withstand much higher intensities of light than the older stages (Russell 1931). Probably the great increase in temperature in the discontinuity layer causes the majority of the population to remain there during the night.

Bonnefjord; 26.—27. June 1947. Number per 1000 litres.

| Depth | 1800 hrs. | 2400 hrs. | 0830 hrs. | 1000 hrs. | 1030 hrs. |
|---|---|---|---|---|---|
| 4 m. | 8 | 11 | 1 | 0 | 0 |
| Discontinuity layer | 347 | 373 | 20 | 38 | 27 |
| 25 m. | 22 | 28 | 41 | — | — |

They reached the upper boundary at about 1800 hrs. and remained in the vicinity till morning. In the daytime they were probably moving about in the lower region of the discontinuity layer.

*Lensia conoidea* (Keferstein and Ehlers 1860). Syn. *Diphyes conoidea*

(Keferstein and Ehlers), *Diphyes truncata* (Sars 1846), *Galetta truncata* (M. Sars 1846), *Galeolaria* (Moser 1925), *Lensia truncata* (Totton 1932).

The superior and inferior nectophores occurred separately, but were counted in pairs. They were found only at 25 m. depth. The determining factor was probably temperature. The figures mentioned below give the total number of *Lensia conoidea* in the whole volume of water passing through the samplers at 25 m.

| Time | 1800 hrs. | 2400 hrs. | 0830 hrs. |
|---|---|---|---|
| Number | 30 | 75 | 24 |

These figures indicate a diurnal migration in the deeper strata.

*Aglantha digitalis* (O. Fr. Müller). The highest temperatures at which *Aglantha digitalis* was common in Danish waters during the summer of 1911 were 13·5°—13·6°C. (24—0 m. on 5. July in the Skagerak), and the highest temperatures in which it has been found are 14·1°—14·3°C. (12—0 m. on 4. July in the northern Kattegat), according to K r a m p 1927. In Bonnefjord on 26. June at 2330 hrs. the discontinuity layer lay in 9—13 m. with temperatures of 19°—7°C. At 10·65 m. depth, where the sample was taken, the temperature was 14°—15°C. (see also *Sarsia tubulosa*, where the hydrographical conditions in the discontinuity layer are described).

Bonnefjord; 26.—27. June 1947. Number per 1000 litres.
(Total number in the samples in brackets.) At the stations not mentioned 0 specimens were found.

| Depth | 1800 hrs. | 2400 hrs. | 0830 hrs. |
|---|---|---|---|
| 4 m. | 0 (0) | 0 (0) | 0 (0) |
| Discontinuity layer | 0 (0) | 44 (176) | 0 (0) |
| 25 m. | 0 (0) | 4 (22) | 0·3 (2) |

In the prevailing hydrographical situation the discontinuity layer, with its rapidly increasing temperature, formed an insurmountable barrier. In the summer the maximum temperatures for the occurrence of *Aglantha digitalis* seem to be about 15°C.

**4. Species on which the discontinuity layer has little or no influence.**

*Calanus finmarchicus* (Fig. 8). Copepodite stage V. During the night the population was evenly distributed between 4 and 25 metres; it was probably distributed in this manner from the surface to below 25 m. At 2400 hrs. the relation between the numbers at 4 m. and in the discontinuity layer was 1 to 1·2; between the numbers at 4 m. and 25 m., 1·6 to 1; and between the numbers in the discontinuity layer and 25 m., 2 to 1. In the daytime the distribution did not extend appreciably above the discontinuity layer. Copepodite stage V has a more uniform vertical distribution than the adults.

Considering the total population at different depths at different periods in the 24 hours, we can see that the strongest movements occur in the uppermost water-layers, where extensive accumulations occur at night. At the same time the quantity in the discontinuity layer is reduced to one-third of the number found there in the daytime. On

the other hand, the number at 25 m. remains constant (3505, 2090, 2555 individuals per 1000 litres).

The material discussed is on the whole too small to permit the drawing of general conclusions on the vertical distribution and migrations of the separate species. Most of the results obtained will only hold good in the prevailing hydrographical situation and in the season in question. Nevertheless they afford certain useful pointers for similar investigations in future.

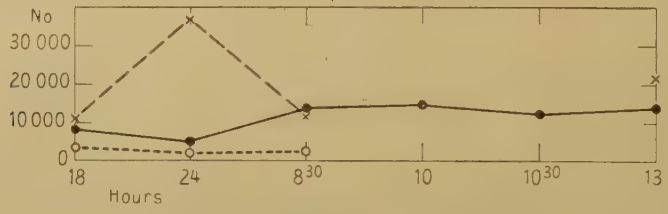


Figure 9. Diurnal variation in the total population (per 1000 litres; at 4 m. ×, the discontinuity layer ●, and 25 m. ○) at all stations.

The hydrographical data should be extended to include investigations (a) on the salinity, (b) on the oxygen content, and (c) in the daytime, on the intensity of light: to determine the factors which limit the distribution of the separate species. In a similar manner a number of Clarke-Bumpus samplers should be arranged in series at short distances from each other. In an area like that investigated, with a marked discontinuity layer at about 10 m., 5 samplers would be sufficient; 2 between the surface and the discontinuity layer, 1 in this layer, and 2 between this and 25 m. or deeper. This would give an accurate picture of the boundary areas for the several species. At the same time vertical hauls, between the discontinuity layer and the surface, and, for example, from 25 m. to the discontinuity layer, should be made in conformity with earlier practice. At the same localities at regular intervals throughout the year, full investigations should be made on the annual cycle of the separate species and their relation to the factors mentioned.

## Summary.

To investigate the possible importance of the discontinuity layer as a limiting factor in the vertical distribution and migrations of the zooplankton, samples were collected from 26.—27. June 1947 from the innermost part of Oslo fjord. The position of the discontinuity layer was determined by means of the bathythermograph. Three Clarke-Bumpus samplers were kept open for ten minutes at 4 m. depth, in the discontinuity layer (9—10·65 m. depth) and at 25 m. depth. The volume of water streaming through the samplers varies from 3,700 to 6,300 litres. Investigations at the stations were made on 26. June at 1800 hrs. and at 2400 hrs.; on 27. June at 0830, 1000, and 1030 hrs. The populations were calculated per 1000 litres. The vertical distribution and migrations of the separate species proved in the main to be as follows:—

1. Species which occur mainly in the warm surface water with the discontinuity layer as its chief boundary: *Calanus finmarchicus* females; *Centropages hamatus* females, males, copepodites; *Oithona nana* females, males, copepodites; *Podon* spp. (see the text); *Evadne nordmanni*.
2. Species which occur in or near the discontinuity layer: *Calanus finmarchicus* males; *Temora longicornis* females, males, copepodites; *Oithona helgolandica* females, males, copepodites; *Sarsia tubulosa*.
3. Species found under the discontinuity layer with this layer as the chief upper boundary: *Pseudocalanus minutus* females, males; *Oncaea borealis* females, males, copepodites; *Meganyctiphanes norvegica; Sagitta* spp. (see the text); *Lensia conoidea; Aglantha digitalis*.
4. Species on which the discontinuity layer has little or no influence: *Calanus finmarchicus* copepodite stage V.

Variation in the total number of individuals in the 24 hours cycle (per 1000 l.):—

4 m. The numbers increased from 11,000 in daytime to 36,300 at night.

Discontinuity layer. The population at night was only one-third of that in daytime (this was constant at about 13,000).

25 m. The population showed no essential change (constant at about 2,500).

I wish to express my sincere thanks to Prof. J. T. Ruud, Oslo, and to my present chief Dr. P. Jespersen, Copenhagen, for their valuable help.

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# A Comparison of the Pre-War and Post-War Stocks of Lemon Soles at Faroe.

By

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## 1. Introduction.

The present study deals with one of the less numerous species of food fishes, the lemon sole, which although landed in relatively small quantities on the British market, nevertheless is of prime importance to Scottish fisheries. For this purpose the Faroe area has been chosen for study as it presents certain features not all found together in other areas. In the first place the Faroe plateau is surrounded by deep water channels and thus may be regarded as self-contained for all demersal species with the exception perhaps of adult cod and halibut; secondly, the area fished for lemon soles is comparatively small in extent besides being confined almost entirely to the plateau immediately surrounding the islands; thirdly, the area was, during the 1930's, subjected to a very heavy fishing intensity, which was considerably reduced in 1939, yet was never at any time entirely discontinued throughout the war; finally, the British catch from Faroe is entirely by otter trawl.

Material for the preparation of this paper has been obtained from three sources:—

(a) English and Scottish fishery statistical records.
(b) Records from cruises of research vessels mainly prior to 1940.
(c) Measurements and scale sampling of commercial catches landed at Aberdeen fish market since 1945.

Under the second category, in addition to Scottish records, much useful material has been provided by Dr. Å. V. T å n i n g, of Copenhagen, to whom our thanks are due. We are also indebted to owners and skippers of Aberdeen trawlers and to Aberdeen fishmerchants for permission to sample the shots referred to in the third category, and finally to the Senior Fishery Officer at Aberdeen and to members of

his staff who have given valuable assistance in connexion with the work.

## 2. Examination of the Pre-War Stocks.

### (a) Commercial Landings.

Reference to the fishery statistical tables shows that from 1922 onwards increasing numbers of British trawlers fished the Faroe area and as a result the total landings of lemon soles increased from 12,674 cwt. in that year to almost 40,000 cwt. in 1932. From 1922 to 1929 the average annual catch of lemon soles by British trawlers at Faroe was 17,632 cwt. and from 1930 to 1938, 27,947 cwt., an increase of over 10,000 cwt.

Since 1922 the contribution from Faroe has varied from 11 % to 24 % of the annual British catch of lemon soles from all areas. It is convenient in the present study to start with the year 1930 as marking the beginning of the period of most intensive fishing and Table 1 gives totals of the British catch up to 1938.

**Table 1. British Trawlers - Faroe.**

| Year | Number of trips | Number of hours fishing | Total weight of lemon soles cwt. | Average catch of lemon soles per 100 hours fishing, cwt. |
|---|---|---|---|---|
| 1930 | 2378 | 176,513 | 23,807 | 13·5 |
| 1931 | 3303 | 273,586 | 36,446 | 13·3 |
| 1932 | 3393 | 291,938 | 39,648 | 13·6 |
| 1933 | 3023 | 287,612 | 33,932 | 11·8 |
| 1934 | 2774 | 272,370 | 24,412 | 9·0 |
| 1935 | 2765 | 287,965 | 26,037 | 9·0 |
| 1936 | 2891 | 283,839 | 23,256 | 8·2 |
| 1937 | 2099 | 205,051 | 17,910 | 8·7 |
| 1938 | 1994 | 192,279 | 26,079 | 13·6 |

Table 1 and Figure 1, which illustrates it, show that the total catch increased up to the year 1932, which was also the record year for the number of trips and number of fishing hours. Thereafter, despite an effort to maintain the fishing intensity, most noticeable in the fishing hours, the catch of lemon soles fell rapidly. This growing scarcity of lemon soles, together no doubt with a scarcity of other species, resulted in the withdrawal of a large number of vessels from Faroe between 1936 and 1937 so that the 1937 catch of lemon soles was the lowest for the period under review. A further withdrawal of fishing power in 1938, however, was marked by a big improvement in the landings of lemon soles. During this period the average catch per 100 hours fishing (column 5 of Table 1) was high at first, reaching a maximum in 1932, after which it fell to its lowest value in 1936. After a slight rise in 1937 a sudden and marked increase was registered in 1938 to equal the previous best average for 1932. This improvement in the lemon sole fishery during 1938 will be discussed later.

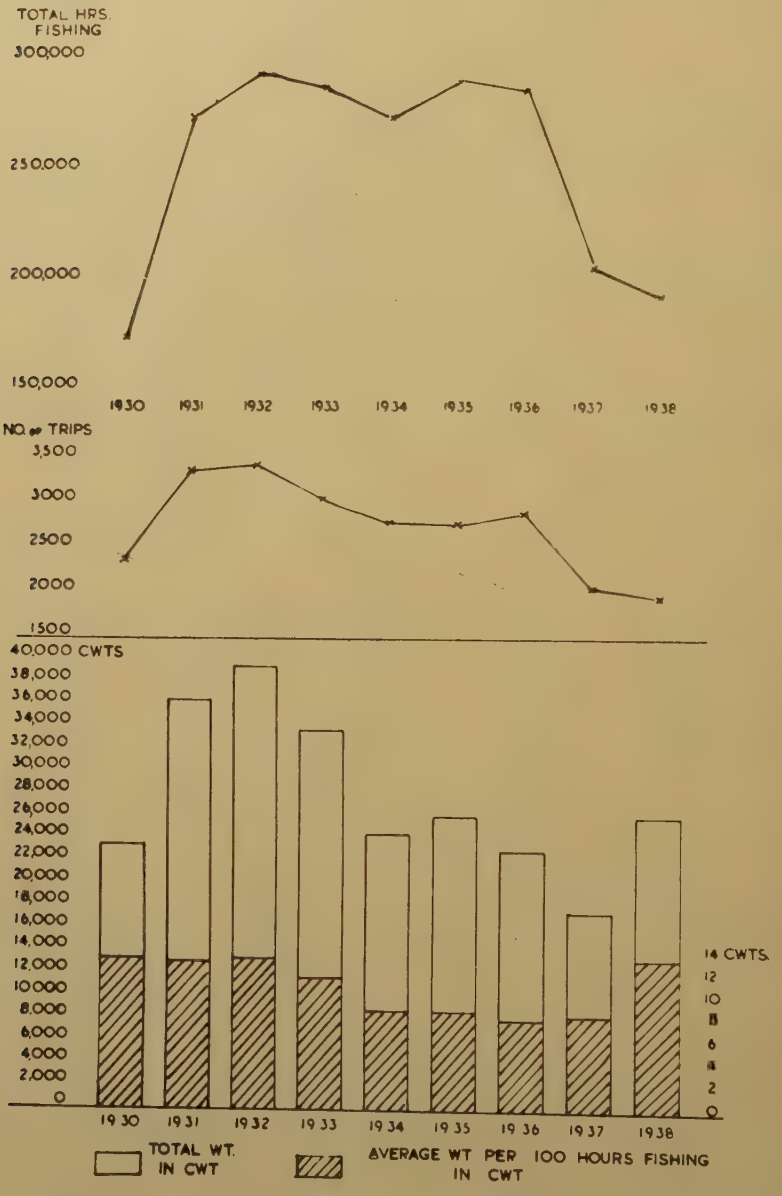


Figure 1. British Trawlers — Faroe, 1930—1938.

Number of trips.
Total hours fishing.
Total catch of Lemon Soles in 1000 cwt.
Average catch of Lemon Soles per 100 hours fishing in cwt.

The increase in the British trawling effort at Faroe during the 1920's and 1930's was to a large extent due to the arrival on these grounds of Scottish vessels, almost entirely from Aberdeen. Although the haddock is the species mainly sought after by Scottish trawlers many Aberdeen skippers were, between the two great wars, encouraged to fish for lemon soles as a result of the high prices obtained for this species. This development took place after the introduction of the V.D. gear and the opening up of grounds hitherto untrawlable by the more general use of heavy groundropes and bobbins and as a result good catches of lemon soles were taken from the north-western North Sea. When the North Sea stocks became depleted, skippers specializing in lemon soles turned to Faroe and in particular to the more prolific grounds round the northern half of the islands. This tendency to fish the northern grounds has been maintained up to the present and, accordingly, Aberdeen lemon sole landings from Faroe may be taken as representative of these grounds.

Table 2 gives details of the landings at Aberdeen from 1930 to 1939. It will be observed that as in Table 1, the highest yearly totals were

**Table 2. Lemon Sole Landings by Scottish Trawlers from Faroe 1930—1939.**

| Year | Number of trips | Total number of hours fishing and number per trip | Weight of lemon soles landed and catch per 100 hours fishing, in cwt. | | | |
|---|---|---|---|---|---|---|
| | | | Large | Medium | Small | Total |
| 1930 | 623 | 46226 | 2518 | 2024 | 2137 | 6679 |
| | | 74·2 | 5·4 | 4·4 | 4·6 | 14·4 |
| 1931 | 876 | 64206 | 2874 | 3051 | 5259 | 11184 |
| | | 73·3 | 4·5 | 4·7 | 8·2 | 17·4 |
| 1932 | 811 | 57735 | 2143 | 3359 | 6392 | 11894 |
| | | 71·2 | 3·7 | 5·8 | 11·1 | 20·6 |
| 1933 | 811 | 64312 | 2093 | 3059 | 5688 | 10840 |
| | | 79·3 | 3·3 | 4·8 | 8·8 | 16·9 |
| 1934 | 686 | 53313 | 1477 | 2044 | 3913 | 7434 |
| | | 77·7 | 2·8 | 3·8 | 7·3 | 13·9 |
| 1935 | 683 | 58931 | 1517 | 2220 | 4080 | 7817 |
| | | 86·3 | 2·6 | 3·8 | 6·9 | 13·3 |
| 1936 | 888 | 75640 | 1656 | 2237 | 4934 | 8827 |
| | | 85·2 | 2·2 | 3·0 | 6·5 | 11·7 |
| 1937 | 650 | 54783 | 959 | 1323 | 3718 | 6000 |
| | | 84·3 | 1·8 | 2·4 | 6·8 | 11·0 |
| 1938 | 624 | 58934 | 1421 | 2144 | 6940 | 10505 |
| | | 94·4 | 2·4 | 3·6 | 11·8 | 17·8 |
| 1939 | 367 | 34438 | 798 | 1287 | 3549 | 5634 |
| | | 93·8 | 2·3 | 3·7 | 10·3 | 16·4 |

obtained in the first half of the period and that although the Aberdeen totals are seldom more than a third of the British totals the catch per unit of fishing time for the Aberdeen vessels is always the greater. This is due to the Aberdeen skippers specializing both in time and place in the search for lemon soles. Again, as in Table 1, the average catch per unit of fishing time rises to a peak in 1932 — more rapidly in the present instance since the Scottish effort to catch lemon soles at Faroe was developing rapidly in the early 1930's. After 1932, however, a fall, similar to that in Table 1, is experienced, to a minimum of 11 cwt. in 1937 after which a sharp recovery is shown for 1938. The catches per unit of fishing time during the four most productive months for lemon soles, i.e., May to August inclusive, although naturally much higher than for the complete year, show the same general trend and for that reason are not reproduced separately.

**(b) Market Categories.**

The size composition of the commercial catches is obtained from their classification in the market categories. The separation of the fish into the various categories is performed by the fishermen or market porters; although the division is necessarily a rough one it is surprising how closely the selections in each category resemble each other throughout the year. In general the size-range and average size of lemon soles in the three main categories are as follows:—

| | | |
|---|---|---|
| Small | — 25 to 35 cm. | — average 29 to 30 cm. |
| Medium | — 30 to 40 cm. | — average 34 to 35 cm. |
| Large | — 35 to 45 cm. | — average 39 to 40 cm. |

Table 2 shows that in 1930 the average catch of large lemon soles was almost $5\frac{1}{2}$ cwt. per 100 hours fishing and that this was more than one-third of the total weight of this species (see also Figure 2). From that year onwards, however, the average weight of large fish declined steadily until in 1937 less than 2 cwt. were taken in the same unit of

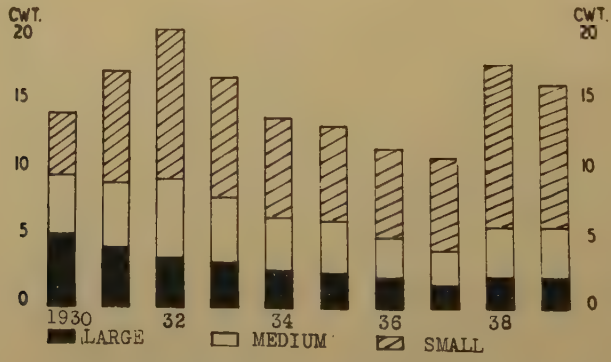


Figure 2. Composition of average catch of Lemon Soles per 100 hours fishing by Scottish trawlers at Faroe, 1930—1939 (from market categories).

fishing time. Thus in the course of 8 years the average weight of large fish fell to one-third of its original figure. In the medium-size category the fall was also appreciable, from a maximum of 5·8 cwt. in 1932 to a minimum of 2·4 cwt. in 1937.

In the "smalls" category, on the other hand, the average weight of lemon soles per unit of fishing time was 4·6 cwt. in 1930, which has proved to be the lowest figure in this size-group for any year in the period under review. After rising quickly to 11·1 cwt. in 1932 it fell to 6·5 cwt. in 1936, since when it has again risen to reach a maximum of 11·8 cwt. in 1938. Thus, in spite of rather marked fluctuations in the average catch of small lemon soles, the tendency was for the landings in this category to increase throughout the period 1930—1939. The possibility of these fluctuations in the landings of small fish being due to brood survival will be considered later, but whatever the cause, it is clear that fishermen were endeavouring to make good the diminishing landings of large and medium-sized fish by increased landings of small fish.

Finally, attention should be drawn to the average number of hours spent on fishing during each trip. From 73 hours per trip during the first three years (1930—1932) trips were extended to an average of 90 hours in the years 1937—1939 — an increase of 17 hours or approximately one complete day, assuming that fishing is possible throughout the greater part of the twenty-four hours. This reflects the greater scarcity of all kinds of fish, including lemon soles, on these grounds and clearly demonstrates the greater effort required to procure a profitable catch.

**(c) Research Vessel Records.**

Turning now to the research vessel records from 1924—1939, it has already been shown (R a e 1939b) that years of good, medium, or poor recruitment have followed each other in a manner similar to that found for the species in other areas. Six years of good brood survival have been identified — 1918, 1920, 1921, 1927, 1930, 1934 — and five of poor survival — 1919, 1922, 1925, 1931, 1933 — while the remaining years have occupied positions of intermediate strength. From the same data average sizes have been calculated and show that growth over northern Faroese grounds (i.e., north of latitude 61°45′N.) is good by lemon sole standards elsewhere, while falling off to a medium rate round the southern end of the islands.

Although it is known from marking experiments (R a e 1939a) that small numbers of lemon soles migrate from northern to southern grounds one should have expected, if losses from natural and fishing mortality were the same on both grounds, that the northern grounds would contain at least the same proportion of large fish as the southern. In the early years of these investigations this would appear to have been so, but after 1930 the proportion of large fish on the northern grounds began noticeably to decline, with the result that the research records in 1939 show the size-frequencies given in Table 3.

**Table 3. Size-Frequencies of Lemon Soles at Faroe June—August, 1939.**
**Research Vessel Records.**

| Size-Group | North Coast | | Nolsø/Svino | | Southern Grounds | | Territorial, 3′E.N.E. of Buen | |
|---|---|---|---|---|---|---|---|---|
| | Number | % | Number | % | Number | % | Number | % |
| 11—15 cm. | 14 | 6·8 | 6 | 0·9 | 3 | 3·2 | — | — |
| 16—20 cm. | 56 | 27·1 | 95 | 14·0 | 6 | 6·5 | 14 | 6·7 |
| 21—25 cm. | 57 | 27·5 | 116 | 17·1 | 8 | 8·6 | 20 | 9·6 |
| 26—30 cm. | 35 | 16·9 | 240 | 35·3 | 16 | 17·2 | 55 | 26·4 |
| 31—35 cm. | 33 | 15·9 | 172 | 25·3 | 27 | 29·0 | 78 | 37·5 |
| 36—40 cm. | 10 | 4·8 | 47 | 6·9 | 29 | 31·2 | 34 | 16·3 |
| 41—45 cm. | 2 | 1·0 | 4 | 0·6 | 4 | 4·3 | 7 | 3·4 |

Columns 1 and 2 refer to grounds north of 61°45′N. and column 3 to grounds south of this latitude. Column 4 represents territorial waters adjacent to the Nolso-Svino grounds. It has previously been shown that the north coast grounds support a higher proportion of small and young fish than do other Faroese grounds — a feature which is evident from Table 3, but in none of the earlier years has the scarcity of large fish in this area been so marked as in 1939. For the present, however, it is sufficient to note the difference in the proportions of large and small fish on grounds north and south of 61°45′N. At the same time the higher proportion of large fish in territorial waters (3′ E.N.E. of Buen) as compared with the neighbouring extra-territorial Nolsø-Svinø grounds is also significant.

**Table 4. Age-Composition of Lemon Soles at Faroe June—August, 1939.**
**Research Vessel Records.**

| Age-Brood | | North Coast | | Nolsø/Svinø | | Southern Grounds | | Territorial 3′E.N.E. Buen | |
|---|---|---|---|---|---|---|---|---|---|
| | | Number | % | Number | % | Number | % | Number | % |
| 2+ | 1937 | 15 | 7·2 | 3 | 0·4 | 2 | 2·2 | — | — |
| 3+ | 1936 | 82 | 39·6 | 92 | 13·5 | 4 | 4·3 | 19 | 9·1 |
| 4+ | 1935 | 61 | 29·5 | 148 | 21·8 | 3 | 3·2 | 26 | 12·5 |
| 5+ | 1934 | 39 | 18·9 | 263 | 38·7 | 28 | 30·1 | 63 | 30·3 |
| 6+ | 1933 | 1 | 0·5 | 41 | 6·0 | 5 | 5·4 | 10 | 4·8 |
| 7+ | 1932 | 3 | 1·4 | 43 | 6·3 | 4 | 4·3 | 25 | 12·0 |
| 8+ | 1931 | 2 | 1·0 | 21 | 3·1 | 11 | 11·8 | 14 | 6·7 |
| 9+ | 1930 | 3 | 1·4 | 47 | 6·9 | 9 | 9·7 | 20 | 9·6 |
| 10+ | 1929 | — | — | 9 | 1·3 | 8 | 8·6 | 7 | 3·4 |
| 11+ | 1928 | — | — | 5 | 0·7 | 6 | 6·5 | 6 | 2·9 |
| 12+ | 1927 | — | — | 5 | 0·7 | 10 | 10·7 | 14 | 6·7 |
| 13+ | 1926 | — | — | — | — | 3 | 3·2 | 1 | 0·5 |
| 14+ | 1925 | 1 | 0·5 | 2 | 0·3 | — | — | 1 | 0·5 |
| 15+ | 1924 | — | — | — | — | — | — | — | — |
| 16+ | 1923 | — | — | 1 | 0·2 | — | — | 2 | 1·0 |
| | Totals | 207 | 100 | 680 | 100 | 93 | 100 | 208 | 100 |

The age analysis of these fish is given in Table 4. This reveals that stocks of lemon soles on northern extra-territorial grounds consisted predominantly of young fish in 1939 and that the scarcity of large fish on these grounds was due to a scarcity of the older fish, while the higher proportions of this category on southern grounds and on northern territorial grounds were the result of the presence of greater numbers of older fish. Thus the percentages of broods of 9 years of age and over total 10 % on Nolsø-Svinø grounds, 2 % off the north coast, 39 % south of 61°45′N. and 25 % off Buen. These figures bear out the Aberdeen market statistics in showing the composition of the lemon sole stocks round the northern half of the Faroes to be made up predominantly of small or young fish prior to 1939.

**d) Average Sizes.**

For comparison with earlier figures the average sizes for the different age-groups in 1939 have been calculated and are reproduced in Table 5 and Figure 3 together with the nearest comparable averages for two periods 1925—1931 and 1933—1938. In order to avoid, as far as possible, the effect of local differences in growth-rate, records from the Nolsø-Svinø extra-territorial area only have been utilized for this purpose. It will be observed that, of the nine averages for the years 1933—1938, two show increases over the corresponding averages for 1925—1931, one is the same at its earlier counterpart, and six

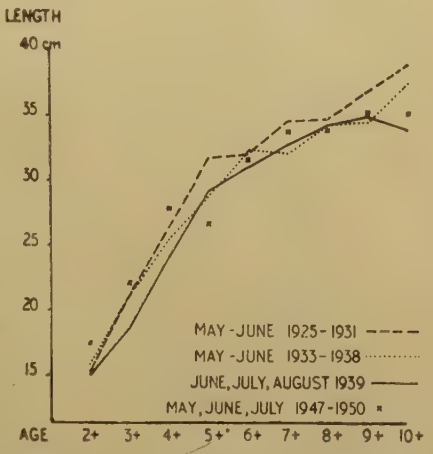


Figure 3. Average Sizes of Lemon Soles, Faroe — Nolsø/Svinø Grounds.

**Table 5. Average Sizes in cm. of Lemon Soles caught by Research Vessels on Nolsø—Svinø Grounds.**

| | Age | 2+ | 3+ | 4+ | 5+ | 6+ | 7+ | 8+ | 9+ | 10+ |
|---|---|---|---|---|---|---|---|---|---|---|
| May, June 1925—1931 | Number | 46 | 16 | 39 | 25 | 26 | 19 | 16 | 12 | 6 |
| | Mean | 15·3 | 21·2 | 26·4 | 31·8 | 32·0 | 34·4 | 34·6 | 36·7 | 38·8 |
| May, June 1933—1938 | Number | 24 | 54 | 15 | 27 | 31 | 44 | 21 | 9 | 7 |
| | Mean | 15·7 | 21·2 | 25·5 | 28·8 | 32·3 | 32·0 | 34·1 | 34·3 | 37·3 |
| June, July, August 1939 | Number | 3 | 92 | 148 | 263 | 41 | 43 | 21 | 47 | 9 |
| | Mean | 15·0 | 18·7 | 24·2 | 29·2 | 31·0 | 32·7 | 34·1 | 34·7 | 33·8 |
| May, June, July 1947—1950 | Number | 8 | 72 | 136 | 5 | 42 | 36 | 33 | 40 | 49 |
| | Mean | 17·5 | 22·1 | 27·9 | 26·6 | 31·5 | 33·6 | 33·8 | 35·1 | 35·0 |

show decreases. Of the 1939 averages three show increases over the 1933—1938 figures, one is the same, and five show decreases, while all nine age-groups show decreases from the 1925—1931 averages. It should also be noted that the 1939 averages are based on records collected in June, July, and August as against May and June of the two earlier periods and have thus the advantage of one month's increment during the fastest growing season. It is reasonable to expect, therefore, that had averages been obtained for the same months in 1939 the differences in the values would have been still more pronounced.

A similar decrease in the average sizes was found for the Myggenæs-Myling Head area off the north coast. On grounds south of 61°45′N., however, the position was found to be markedly different. No fewer than five of the eight age-group average sizes showed increases over their corresponding averages for the combined periods 1925—1931 and 1933—1938. In view of the smaller numbers of fish dealt with in this area, however, it is not proposed to stress these increases. It is sufficient at this point to note that no general decrease was found on southern grounds such as has been demonstrated for northern grounds.

**(e) Summary of Results.**

The following points have emerged from this study of the lemon sole stocks at Faroe prior to 1939:—

1. From 1932 to 1937 the total British catch of the species from all Faroese grounds fell by over 50 % and the average catch per unit of fishing time by 40 %.
2. During the same period the total catch by Aberdeen trawlers from northern Faroese grounds and the average per unit of fishing time each fell by about 50 %.
3. From 1930 to 1937 the proportion of large lemon soles in the Aberdeen catches from northern grounds fell by 66 %.
4. From research records the stocks on northern grounds in 1939 consisted predominantly of small fish; on southern grounds and in territorial waters adjacent to the northern grounds the stocks included considerable numbers of large fish.
5. After reaching a maximum in 1932 the British fishing effort dropped slightly but continued at a high level until 1937 when a sharp fall occurred in the number of trawlers fishing Faroese grounds.
6. The average sizes for the various age-groups on northern grounds in 1939 were lower than for earlier years. That this decline had been in operation before 1939 is shown by the generally lower averages for the period 1933—1938 as compared with 1925—1931. No such decrease was found on southern grounds.
7. A marked improvement in the total catch and average per unit of fishing time both in British and in Aberdeen landings was recorded for 1938 and 1939.

**(f) Discussion and Conclusions.**

In considering these points it is necessary to bear in mind certain facts relating to the biology of the lemon sole:—

a. Growth is slow in comparison with that of certain other species.
b. Stocks are composed of a larger number of age-groups than are stocks of other species in the same area.
c. There is no sharp separation in the distribution of adolescent and adult fish as with the plaice and turbot, for example.
d. The ratio of the strength of good to poor broods is low (6—1) in comparison with the haddock, for example (60—1).
e. Spawning varies from place to place but is heaviest during June, July, and August when feeding too is at its highest. The heaviest catches are obtained at this time on Faroese grounds.

The result of the high fishing intensity at Faroe from 1932 to 1937 was reflected in rapidly declining landings of lemon soles and in falling catches per unit of fishing time for all northern grounds. Both commercial catches and research vessel records emphasize the growing scarcity of large fish and the increasing dependence on small lemon soles for the maintenance of the landings from the northern grounds during the 1930's. These findings clearly indicate that the stocks of lemon soles on northern Faroese grounds were being subjected to considerable strain during these years if not actually to overfishing. The contrast in the size- and age-composition of the fish with those on southern grounds and on adjacent territorial grounds emphasizes the difference in the nature of the stocks. Few Aberdeen trawlers fish the southern grounds and, while English vessels undoubtedly do so with success, it is clear that for various reasons, the intensity of fishing per unit of area south of 61°45′N. is very much less than on grounds to the north of this latitude, thus permitting the survival of larger numbers of older fish.

With regard to the decreases observed in the average sizes of the various age-groups on northern grounds in 1939 and also to a less extent from 1933—1938 it has been shown that the reduction of a dense stock of fish results in an improved growth-rate among the survivors (Petersen 1925, Poulsen 1938, Raitt 1939). This has also been found for the lemon sole in Scottish waters (unpublished results). If the rate of fishing on any stock, however, should reach the "overfished" stage, then, with the rapid elimination of the faster growing individuals as they reach the catchable size, the effect would be lowered average sizes and the appearance of a depressed growth-rate. It is suggested, therefore, that the lowered averages for the northern Faroese grounds in 1939 and preceding years might be another effect on the stock of the high intensity of fishing in the 1930's. Again the more normal averages for southern grounds, which were not so heavily fished in the same period, seem to support this view.

One point remains to be examined — the sudden improvement in the catch in 1938. Reverting to Table 1 we may recall that the number of trips by British trawlers to Faroe declined sharply after 1936. In 1937, 792 fewer trips were made than in 1936, representing nearly 80,000 fewer hours fishing or more than 27 % of the 1936 total. It is

considered, therefore, that this sudden decrease, following a more gradual decrease from 1932 onwards, in the catching power at Faroe, is the chief cause of the marked improvement in the lemon sole catch in 1938. With fewer vessels operating there would, naturally, be more fish available on the grounds, and for a longer period, thus ensuring larger catches. This may be readily appreciated if regard is had to the nature of the trawl fishery at Faroe with its heavy concentration of vessels in small areas.

A detailed examination of the monthly landings shows that about 1934 trawling began to be more heavily concentrated in the summer months, at the time when catches of lemon soles are heaviest. This also undoubtedly contributed to the maintenance of the total catch and of the average per unit of fishing time for these years and particularly for 1938.

It may be argued that the 1938 increases could be caused by the appearance of another prolific brood. This, however, would affect the landings of small fish only, in 1938, but, as Table 2 shows, large and medium sized fish also increased in quantity. Moreover, owing to the number of broods represented in a stock at any time and to the comparatively small variation in the strength of broods, the appearance of a new brood does not have the same effect on commercial catches as in some other species and is seldom recognized in the landings.

It must be concluded, therefore, that the improvement in 1938 was chiefly due to the reduction in the fishing effort in the immediately preceding years, which permitted the survival of a larger number of fish for a longer period with the consequent gain by growth and weight. The resultant stock of fish was then available for exploitation by the smaller number of vessels and better catches ensued. This conclusion is similar to that formed by Hickling (1946) in his examination of the hake fishery off the south-western shores of the British Isles.

### 3. Trawling at Faroe during the War.

Throughout the greater part of the war fishing at Faroe was unrestricted to the north of latitude 61°45′N. except for a relatively small area north-west of the islands. In this area and on southern grounds trawling was prohibited because of minefields. With the development of the war and with the consequent requisitioning of trawlers for naval duties the numbers of trawlers based on British ports were much reduced and the numbers of trips to all grounds including Faroe declined simultaneously. For various reasons the number of trips to Faroe varied from year to year during the war and post-war period. The following averages represent the numbers of trips and numbers of hours fishing by British trawlers during the periods 1930—1938 and 1941—1946:—

| | Average annual number of trips | Average annual number of hours fishing |
|---|---|---|
| 1930—1938 | 2736 | 252,350 |
| 1941—1946 | 627 | 58,897 |
| % of pre-war average | 22·9 | 23·3 |

These figures show that as a result of the war, trawling activity on northern Faroese grounds was reduced to less than a quarter of the pre-war effort. This represents a considerable relief on the heavy strain previously being placed on these grounds and if the question of horse power is also taken into account, the reduction in effort would certainly be still greater since the vessels left to carry on fishing were generally the oldest and least powerful units of the fleets.

## 4. Examination of the War and Post-War Stocks.

### (a) Commercial Landings at Aberdeen.

Table 6 gives the landings of lemon soles by Aberdeen trawlers from Faroe from 1940 to 1949. Unfortunately, after 1940, the selection of fish into market categories was discontinued with the introduction of controlled prices. It will be observed that the number of trips fell sharply after 1940 and did not increase appreciably until after the war. On the other hand, as the war progressed, trips tended to become longer and this feature continued after the war, encouraged by the Government's desire for quantity of fish rather than quality. Only in 1949, with the prospect of the removal of price controls and the urgent need for better quality of fish, did the duration of trips show any sign of shortening. Despite a much smaller fishing effort than in pre-war years a record landing of lemon soles was made by Aberdeen trawlers from Faroe in 1943. Thereafter, the annual yield continued high, except for a temporary decline in 1945, due to the departure of trawlers for the newly opened North Sea grounds at the height of the Faroe lemon sole season, and in 1947 another record landing was set up. Since that year, the total landings have fallen but the 1949 catch remained considerably higher than the pre-war average.

As regards the average catch per unit of fishing time, Table 6 shows that the improvement for 1938 was maintained and in 1940 had almost reached the previous maximum of 1932. A slight decline occurred in 1941 but in the following five years the average rose steadily, except

**Table 6. Lemon Sole Landings by Aberdeen Trawlers from Faroe 1940—1949.**

| Year | Number of trips | Total number of hours fishing | Average number of hours per trip | Total catch Lemon soles in cwt. | Average catch per 100 hours fishing in cwt. |
|---|---|---|---|---|---|
| 1940 | 687 | 57,483 | 83·7 | 11,025 | 19·2 |
| 1941 | 370 | 28,770 | 77·8 | 4,360 | 15·2 |
| 1942 | 320 | 29,948 | 93·6 | 7,215 | 24·1 |
| 1943 | 481 | 43,189 | 89·8 | 13,551 | 31·4 |
| 1944 | 373 | 40,270 | 108·0 | 13,101 | 32·5 |
| 1945 | 267 | 29,004 | 108·6 | 6,741 | 23·2 |
| 1946 | 366 | 42,640 | 116·5 | 14,158 | 33·2 |
| 1947 | 522 | 64,216 | 123·0 | 19,264 | 30·0 |
| 1948 | 513 | 68,441 | 133·4 | 16,399 | 24·0 |
| 1949 | 580 | 69,520 | 119·9 | 15,045 | 21·6 |

for a temporary fall in 1945, to attain a new maximum of over 33 cwt. in 1946. The subsequent three years saw a steady decline in the catch per unit of fishing time although the figure for 1949 still remained higher than the pre-war maximum.

The tendency, already noted for 1934 and subsequent years, for the fishing effort at Faroe to be concentrated more in the summer months has again made its appearance since the end of the war. Fishing has varied considerably in intensity from year to year in May, which generally marks the beginning of the main lemon sole fishery, and in certain years has fallen away markedly from September to November at the time when lemon sole catches are relatively low. The overall effect of this is that the averages per unit of fishing time for the post-war period are slightly higher as a result of the relatively greater concentration of effort at the height of the lemon sole fishery.

It should be noted, however, that although the post-war fishing effort has increased, it is still far short of the average pre-war effort. Up to the present, the greatest annual post-war effort was recorded in 1947, when 1208 trips were made to Faroe by British trawlers, representing 132,833 hours fishing. These figures comprise 44·2 % and 52·6 % of the corresponding pre-war averages and clearly show that considerably less strain has been put on the Faroese fish stocks in the post-war period than in pre-war years.

**(b) Sampling of Commercial Catches.**

Research investigations at Faroe were suspended throughout the war so that no data are available for studying the change in the nature of the lemon sole stocks during the period of recovery from the condition of the pre-war years. Measurements and the collection of scale samples were commenced in August 1945, first on board commercial vessels at sea and later from catches landed at Aberdeen Fish Market. Sampling was carried out on a regular monthly basis from January 1946 onwards. Although most Aberdeen trawlers fish on more than one ground in the course of a trip, so that the exact origin of the fish sampled is seldom definitely known, it is certain that all the catches were obtained on northern Faroese grounds and that sampling was fairly evenly distributed over the area.

**(c) Size and Age Composition of the Samples.**

The size-frequencies of these catches expressed as percentages are given in Table 7 (see also Figure 4). For comparison the frequencies of research vessel records from the same grounds in 1939 are also included. Only fish of 26 cm. and over have been accepted from the research records in order to eliminate any possible effect of the small mesh covering the cod-end of the trawl.

The change in the size composition of the stock is remarkable. Whereas in 1939 half the lemon soles available for trawlers were small fish of 30 cm. or under, only 15 % were of this size at the end of the war. On the other hand over 50 % of the 1945 stock were over 35 cm. in length as against less than 12 % in this category in 1939.

## Table 7. Size-Frequency Percentages of Lemon Soles caught on Northern Grounds at Faroe.

**Research Records 1939 and Aberdeen Trawler Catches 1945—1949.**

| | <31 cm. | 31-35 | 36-40 | 41-45 | 46-50 |
|---|---|---|---|---|---|
| 1939 | 50·6*) | 37·8 | 10·5 | 1·1 | — |
| 1945 | 15·1 | 32·1 | 39·1 | 13·1 | 0·6 |
| 1946 | 22·5 | 35·4 | 33·7 | 7·8 | 0·6 |
| 1947 | 31·4 | 41·0 | 23·7 | 3·9 | + |
| 1948 | 31·8 | 40·1 | 21·4 | 6·3 | 0·4 |
| 1949 | 34·7 | 39·6 | 21·2 | 4·2 | 0·3 |

*) Fish of less than 26 cm. not included.

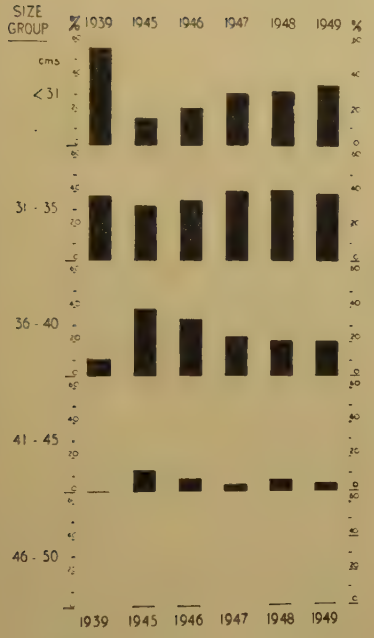


Figure 4.

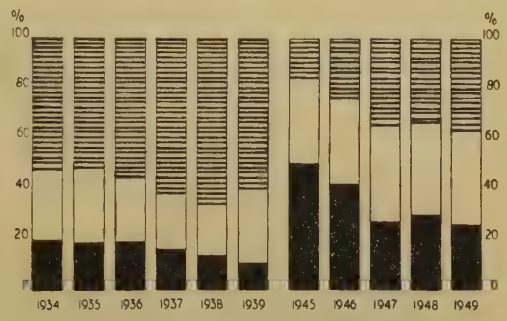


Figure 5.

Figure 4. Size-Frequency Percentages of Lemon Soles caught on northern Faroese Grounds, 1939 (research records) and 1945—1949 (Aberdeen trawlers).

Figure 5. Percentages of the Total Weights of Lemon Soles in each Trade Category from northern Faroese Grounds. — 1934—1938 from market statistics. 1939 calculated from research records. 1945—1949 calculated from Aberdeen trawler records.

## Table 8. Percentages of the Total Weights of Lemon Soles in each Trade Category.

1934—1938 from quantities in each category (Aberdeen trawlers);
1939 (research vessels);
1945—1949 calculated from size-frequencies of market samples (Aberdeen trawlers).

| | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1945 | 1946 | 1947 | 1948 | 1949 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Small | 53 | 52 | 55 | 62 | 66 | 60 | 16 | 23 | 35 | 34 | 37 |
| Medium | 27 | 29 | 25 | 22 | 20 | 29 | 34 | 34 | 38 | 36 | 37 |
| Large | 20 | 19 | 19 | 16 | 14 | 11 | 50 | 42 | 27 | 30 | 26 |

The percentages for the subsequent post-war years indicate a gradual change in the size-composition of the stocks, characterized by increasing proportions of small fish, particularly in the less than 31 cm. group, and by decreasing numbers of large fish of 36 cm. and over.

As already stated the separation of fish into categories in the market was discontinued after 1940 and, up to the end of 1949, had not been resumed. There are, therefore, no figures to indicate the quantities of large, medium, and small fish landed in the post-war years. It has been possible, however, to obtain some useful figures from a knowledge of (a) the number and sizes in a cwt. of lemon soles in pre-war years, and (b) the size frequencies of the post-war samples. In this way figures have been calculated to represent the proportion of the post-war catches in each trade category. The resultant percentages together with those obtained directly from the quantities in each category for a number of pre-war years are set out in Table 8 and illustrated in Figure 5. These again reveal the contrast in the pre-war and post-war stocks, with small fish forming over 60 % of the catch from 1937 to 1939 and only 16 % in 1945 and with large fish represented by a relatively small percentage in 1937—1939 but forming half the catch in 1945. Since 1945 a steady decline in the numbers of large fish has been apparent while small fish have become more numerous.

From research vessel records for 1939 the most numerous broods in the lemon sole catches of that year were those of 1934, 1935, and 1936, with the first of these clearly of outstanding proportions. In 1939 and 1940 the 1934 brood would have been the mainstay of the fishery and thus would have been heavily fished before the war-time restrictions in fishing effort came fully into force.

The age analyses, together with catch per 100 hours fishing and percentages of the post-war commercial catches sampled at Aberdeen, are given in Table 9. This reveals that in 1945, lemon sole stocks were largely made up of four broods — 1935, 1936, 1937, and 1939, with the 1937 brood outstanding. From these and from pre-war records the 1935 and 1936 broods must be regarded as of good-medium strength, although it is doubtful if they would have survived so successfully had they been subjected to a heavy intensity of fishing from the time they first began to appear in the commercial catches. The reductions in the fishing power at Faroe, particularly that of 1940, took place most opportunely for the survival and growth of these two broods.

Figure 6 shows the broods represented in the lemon sole commercial catches during the years 1945—1949 inclusive. Each brood is depicted by a graph illustrating its numerical strength, as determined by catch per unit of fishing time, at each age throughout the 5 years. From this graphical representation the various broods may be classified roughly as follows:—

| | | |
|---|---|---|
| Good recruitment | — | 1937, 1939, 1941, 1943, 1946(?) |
| Good medium „ | — | 1935, 1936 |
| Poor medium „ | — | 1944 |
| Poor „ | — | 1938, 1940, 1942, 1945. |

## Table 9. Aberdeen Trawler Catches on Northern Faroese Grounds 1945—1949.

(a) Age-composition of the samples.
(b) The corresponding catch per 100 hours fishing.
(c) The corresponding percentage.

| Brood | Year 1945 | | | Year 1946 | | | Year 1947 | | | Year 1948 | | | Year 1949 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a. | b. | c. % | a. | b. | c. % | a. | b. | c. % | a. | b. | c. % | a. | b. | c. % |
| 1947 | — | — | — | — | — | — | — | — | — | — | — | — | 2 | 1 | + |
| 1946 | — | — | — | — | — | — | — | — | — | 6 | 2 | 0·1 | 906 | 463 | 17·6 |
| 1945 | — | — | — | — | — | — | — | — | — | 32 | 27 | 1·5 | 120 | 86 | 3·3 |
| 1944 | — | — | — | — | — | — | 21 | 15 | 0·6 | 201 | 163 | 8·9 | 364 | 285 | 10·9 |
| 1943 | — | — | — | 31 | 52 | 2·0 | 357 | 426 | 18·0 | 889 | 557 | 30·4 | 1132 | 784 | 29·9 |
| 1942 | — | — | — | 22 | 47 | 1·8 | 140 | 139 | 5·9 | 191 | 139 | 7·6 | 191 | 124 | 4·7 |
| 1941 | 5 | 83 | 4·5 | 158 | 466 | 17·6 | 503 | 457 | 19·3 | 456 | 276 | 15·1 | 484 | 306 | 11·7 |
| 1940 | 4 | 55 | 3·0 | 32 | 95 | 3·6 | 120 | 133 | 5·6 | 105 | 71 | 3·7 | 106 | 82 | 3·2 |
| 1939 | 19 | 234 | 12·9 | 165 | 520 | 19·6 | 482 | 426 | 18·0 | 383 | 266 | 14·5 | 324 | 260 | 9·9 |
| 1938 | 7 | 100 | 5·5 | 49 | 169 | 6·4 | 144 | 158 | 6·7 | 89 | 64 | 3·5 | 64 | 52 | 2·0 |
| 1937 | 31 | 451 | 24·8 | 146 | 550 | 20·8 | 344 | 368 | 15·6 | 209 | 148 | 8·1 | 157 | 119 | 4·5 |
| 1936 | 27 | 362 | 19·9 | 82 | 392 | 14·8 | 163 | 152 | 6·4 | 119 | 87 | 4·7 | 44 | 28 | 1·1 |
| 1935 | 22 | 290 | 15·9 | 42 | 190 | 7·2 | 56 | 48 | 2·0 | 22 | 14 | 0·8 | 20 | 17 | 0·6 |
| 1934 | 10 | 127 | 7·0 | 24 | 98 | 3·7 | 44 | 30 | 1·3 | 12 | 8 | 0·4 | 14 | 13 | 0·5 |
| 1933 | 4 | 33 | 1·8 | 7 | 40 | 1·5 | 6 | 5 | 0·2 | 6 | 2 | 0·1 | 3 | 1 | + |
| 1932 | 5 | 66 | 3·6 | 2 | 10 | 0·4 | 5 | 3 | 0·1 | 5 | 7 | 0·4 | 2 | 3 | 0·1 |
| 1931 | 1 | 5 | 0·3 | 3 | 12 | 0·5 | 5 | 2 | 0·1 | 1 | 1 | 0·1 | — | — | — |
| 1930 | 1 | 14 | 0·8 | — | — | — | 1 | 1 | 0·05 | — | — | — | — | — | — |
| 1929 | — | — | — | — | — | — | 1 | 1 | 0·05 | — | — | — | — | — | — |
| 1928 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 1927 | — | — | — | 1 | 8 | 0·3 | — | — | — | — | — | — | — | — | — |
| Total | | 1820 | | | 2649 | | | 2364 | | | 1832 | | | 2624 | |

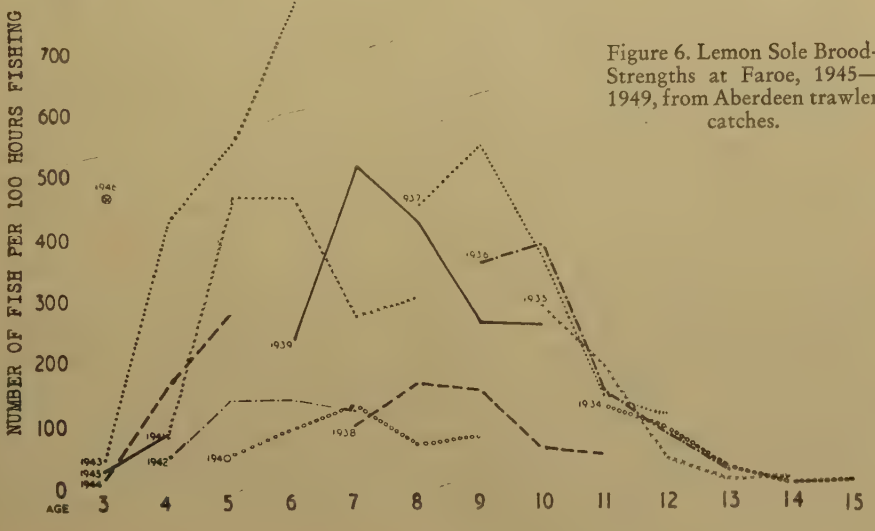


Figure 6. Lemon Sole Brood-Strengths at Faroe, 1945—1949, from Aberdeen trawler catches.

The 1946 brood has been sampled once only but the high figure obtained suggests good survival, although the value may be exaggerated slightly as a result of the more general use of small meshed cod-ends of minimum legal size. Since the discontinuation of sampling of commercial catches at the end of 1949 research records in 1950 have confirmed the good recruitment from the 1946 brood.

**(d) Post-War Research Records.**

Scottish research investigations were resumed at Faroe in 1947. The results add to our knowledge of the lemon sole stocks there and provide useful confirmation of the records obtained from commercial vessels. In particular it is of interest to refer to the average sizes for the various age-groups which have again been calculated for the Nolsø-Svinø area (see Table 5 and Figure 3). These post-war averages are based on measurements in May, June, and July of the four years 1947 to 1950 and are, accordingly, not strictly comparable with any of the earlier series. It is to be noted, however, that in seven out of the nine averages the post-war values are greater than those of 1939, despite the latter series being based on records obtained rather later in the season of maximum growth. This is regarded as evidence of a recovery in the average sizes as a result of less intensive trawling during the war and post-war years and seems to support the view that depressed averages may result from very heavy fishing.

**(e) Discussion and Conclusions.**

In the course of the twelve years 1935 to 1946 there have been five years of outstanding brood survival as compared with six in the previous seventeen years 1918 to 1934. This represents a slightly higher proportion of good broods in the 1935—1946 period — a feature which must have helped to maintain the stocks during the post-war period when fishing effort was again increasing from year to year.

During the years 1946—1949 a marked change may be observed as having taken place in the age-composition of the stocks. Gradually the accumulated stocks of older fish were thinned out and, despite the emergence of a succession of good broods, the proportions of small fish continued to rise. This change took place although the fishing power operating on Faroese grounds was still considerably below that of the pre-war years.

It will be observed from Table 9 that the overall catch of lemon soles per 100 hours fishing after falling from 2649 fish in 1946 to 1832 fish in 1948 (1945 may be ignored as the sampling had not been properly organized then) rose sharply to 2624 fish in 1949. This, however, is not in agreement with the average weight of the species taken per 100 hours by commercial vessels. As Table 6 shows this average has been falling steadily since 1946. It is clear, therefore, that abnormally large numbers of small lemon soles were landed at Aberdeen in 1949. Two prolific young broods, 1943 and 1946, were the source of these small fish. The presence of so many 3-year-old fish (1946 brood) in the

commercial catches, however, is unusual, particularly since a higher size limit for the landing of lemon soles was being imposed in 1949. This suggests either that fishermen were using smaller meshed nets, although still of legal size, during 1949 than in 1945, for example, when a 4-inch-mesh cod-end was in common use, or that a sharper selection of fish was being made by fishermen in order to offset the declining numbers of large fish. From investigation of these points it has been ascertained that although no general use of a smaller mesh has been made at Faroe, the larger numbers of normal North Sea trawlers visiting Faroe in recent years should certainly have resulted in the capture of more small fish, since they employ smaller meshed nets than the vessels regularly fishing at Faroe. At the same time there has undoubtedly been a sharper selection of fish to maintain landings.

In 1940 then, when the catching power was suddenly reduced to a minimum by war needs, the lemon sole stocks at Faroe were improved as a result of the emergence of four successive good or medium-good broods 1934—1937. It has been noted that the reduction of the trawling effort by 27 % between 1936 and 1937 was the chief factor in producing the larger catches in 1938 and 1939. The effect of the considerably greater reductions in trawling effort, to less than a quarter of the pre-war effort, during the war years can, therefore, be appreciated. There is no doubt that this allowed large numbers of lemon soles to attain a larger size before being caught than they would have done under pre-war conditions (see H i c k l i n g 1946). Combined with the unusual succession of good recruitment years from 1934 to 1937 this resulted in the extraordinary catches per unit of fishing time obtained over the period 1943—1947. That this increase in the catch was not confined to lemon sole is revealed by reference to landings of cod, haddock, and plaice, all of which show remarkable increases. All four species attained their maximum yield per unit of fishing time in either 1945 or 1946.

Since 1945 the commercial catches of lemon soles have been characterized by a gradual reduction in the numbers of large fish and by increasing numbers of small fish, although in 1949 the composition of the stock had not reached the depressed condition of the late 1930's.

Two factors have operated against this tendency — the higher-than-average recruitment over the war and post-war periods, and the diminished trawling effort of the post-war years.

## V. Summary of Conclusions.

1. On the evidence of (a) declining landings and catches per unit of fishing time, (b) reduced numbers of large fish, and (c) reduced average sizes for the various age-groups, it is clear that considerable strain was being placed on the lemon sole stocks on northern Faroese grounds in the 1930's by the heavy intensity of trawling.
2. Some relief to this condition was obtained by the withdrawal from Faroese grounds of large numbers of trawlers after 1936.

3. As a result of the big reduction in fishing effort during the war, to less than one-quarter of the average figure for 1930—1938, the average annual catch of lemon soles for the period 1943—1947 was greater by 4000 cwt. or 48 % than the corresponding figure for 1930—38. At the same time the catch per unit of fishing time was doubled.
4. Since 1946, with increasing trawling effort (not yet up to pre-war standards), catches and sizes have been declining but continue to be better than in pre-war years.
5. Finally, it should be possible, by regulating the catching power, to obtain over a period of years something like an optimum annual catch which will at the same time maintain the stocks and provide a steady economic fishery. No attempt is being made at present to do this, as obviously other species must also be considered in this connexion. It is proposed, however, to examine the data dealt with in this paper from a statistical angle with a view to developing some of the conclusions.

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# Some Remarks on the Eggs of Herring (*Clupea harengus* L.) and Capelin (*Mallotus villosus* (O. F. Müll.)) in Icelandic Waters.

By

**A. Fridriksson** and **G. Timmermann.**

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DURING investigations carried out in March-May 1950 to locate the spawning grounds of spring spawning herring south and west of Iceland, herring spawn was found on the sea bottom and a number of haddock stomachs ("spawny haddock") were examined. Large-scale collection of stomachs was organized, and in addition we received occasional samples of stomachs from fishermen who supposed them to be full of herring spawn. On examination in the laboratory, the contents of several of the stomachs from both sources proved to be the spawn of the capelin (*Mallotus villosus* (O. F. Müll.)). Both species often spawn at the same time, on the same banks, and obviously at similar depths, on sandy or gravel bottoms, and they both attach their eggs to the substratum of the bottom. When a search is being made for the spawning grounds of these two species, it is of course essential to be able to distinguish between their eggs with full certainty. However, the general description and the measurements given in the text-books are too vague to permit of accurate discrimination. For instance, according to S æ m u n d s s o n, the eggs of the capelin measure 1 mm. in diameter, those of the herring 1—1·5 mm. Accordingly it might therefore be opportune to give a clearer definition of the difference between the eggs of these two species, which are extremely common (and important) in Icelandic waters.

With regard to colour, newly laid herring eggs are a transparent bluish-grey, but become more and more whitish during hatching. The eggs of the capelin, on the other hand, are a pale violet, or violet-grey. Thus the eggs of the two species are easily distinguishable from each other by their colour, in the first place.

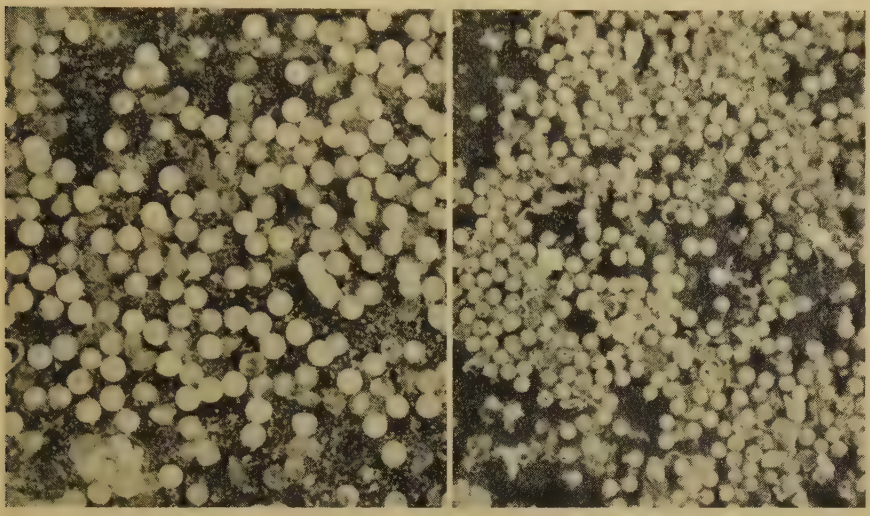
Furthermore, there is a very marked difference in size. According to our measurements of 100 eggs of both herring and capelin, the diameter of the capelin's eggs lies between 0·98 and 1·27 mm., that of the herring's between 1·57 and 1·91 mm., so that the size-ranges of the two egg types do not overlap at all and are separated by an interval of 0·30 mm. This may be clearly seen in the following table.

**Length Variation of Eggs of Herring and Capelin.**

| Length, mm. | Eggs of Herring (number) | Eggs of Capelin (number) |
|---|---|---|
| 1·91 | 1 | — |
| 1·86 | 3 | — |
| 1·81 | 5 | — |
| 1·76 | 12 | — |
| 1·72 | 21 | — |
| 1·67 | 32 | — |
| 1·62 | 18 | — |
| 1·57 | 8 | — |
| 1·52 | — | — |
| 1·47 | — | — |
| 1·42 | — | — |
| 1·37 | — | — |
| 1·32 | — | — |
| 1·27 | — | 1 |
| 1·23 | — | 7 |
| 1·18 | — | 20 |
| 1·13 | — | 37 |
| 1·08 | — | 25 |
| 1·03 | — | 8 |
| 0·98 | — | 2 |
| Total number | 100 | 100 |
| Average diam. | 1·69 | 1·12 |

The eggs of the two species are thus quite easily recognizable by their size, even without measuring instruments, and the difference is immediately apparent as the photographs show.

We should like to take this opportunity to call attention to another feature regarding the size of the eggs of the Icelandic herring. The information on the size of the eggs of herring from different European waters and of different groups contained in the scattered records in the fishery-biological and ichthyological literature is a little indefinite. Despite this, however, it is clear that the size of the eggs of Icelandic spring spawning herring exceeds that of all other European herring stocks. According to the observations of C. Cunningham, E. Ehrenbaum, C. V. Otterstrøm, B. Sæmundsson, and A. Wollebæk, to name but a few authors, there is general agreement that the diameter is 1·0—1·5 mm., while in dwarf races such low figures as 0·85 mm. have been found (Otterstrøm). Einar Lea, on the



Eggs of *Clupea harengus.* Eggs of *Mallotus villosus.*
2 × natural size.

other hand, gives figures for the diameter of the eggs of the Norwegian spring spawning herring ranging between 1·5 and 1·7 mm., but admits that smaller values may be found in other races. As demonstrated above, we have found that the size of the eggs of the spring spawning Icelandic herring ranges from 1·57 to 1·91 mm., or, rounded off, from 1·6 to 1·9 mm. Thus, the figures found by us are in closer agreement with those found by Lea, than with any other records known to us. Nevertheless, our figures are considerably higher than the Norwegian, as the largest Norwegian eggs (1·7 mm.) just reach the average size of the Icelandic ones (1·69). As far as can be seen, the Icelandic spring spawning herring seems to produce larger eggs than any other group of herring in European waters.

# Une Expérience de Marquage sur la Sardine du Golfe de Gascogne.

Par

**R. Letaconnoux.**

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Au cours du mois de Septembre 1950 nous avons pu effectuer un essai de marquage de sardines au large de la Rochelle à bord du sardinier "Anne Rose Marie". Cet essai ayant donné des résultats satisfaisants l'expérience fut reprise au cours du mois d'Octobre et un total de 718 sardines furent marquées. Deux mois après les derniers marquages trois recaptures étaient enregistrées démontrant ainsi la possibilité d'effectuer des marquages sur la sardine malgré sa réputation de poisson très fragile.

Jusqu'à ce jour en effet aucun essai de marquage n'avait été effectué sur la sardine européenne atlantique (*Clupea pilchardus*). Par contre un grand nombre de sardines (*Sardinops caerulea*) avaient été marquées en Colombie Britannique dès 1935 puis en Californie en 1936 et ces observations se sont poursuivies depuis. En Adriatique des expériences importantes de marquages ont également été effectuées en 1948—49 par M u z i n i c à l'aide d'une marque operculaire.

La marque utilisée en Amérique est une petite lame en acier inoxydable que l'on introduit dans la cavité générale du poisson. La sardine est en effet manipulée le plus souvent en grandes masses et une marque externe est rarement remarquée surtout lorsqu'une partie importante de la pêche est utilisée directement par les usines de farine. Dans ce cas la marque se retrouve sur un électro-aimant au moment du tamisage.

En France, où l'industrie de la sardine est différente et où le poisson est souvent trié à bord des bateaux lors de la mise en casiers puis à l'usine de conserve pendant la préparation du poisson, les chances de retrouver une marque externe sont relativement nombreuses.

Les marques que nous avons ainsi utilisées se composent d'une plaquette de celluloïd jaune de 5×25 mm. et d'une agrafe en fil d'acier inoxydable de 0·4 mm. de diamètre. Les agrafes sont de deux types: en broche (A) et à double pointe faisant ressort (B). Le poids d'une telle

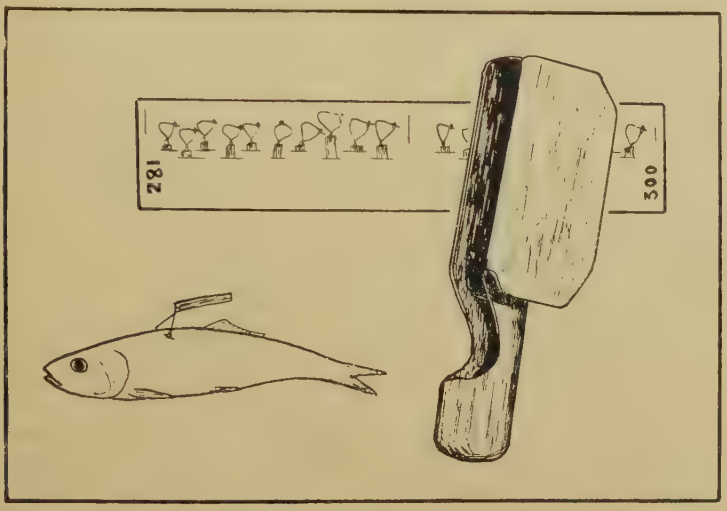


Figure 1. Mode de fixation de la marque sur une sardine, carton de vingt marques et sabot utilisé.

marque est de 0·10 g. environ. Un numéro précédé des lettres R.F. est gravé sur chaque plaquette de celluloïd au moyen d'un appareil à pyrograver à chauffage réduit. Les marques sont ensuite montées et groupées par vingt sur des cartons.

La marque est piquée dans le dos du poisson entre la nuque et la nageoire dorsale, c'est à dire en un point relativement stable du corps pendant la nage.

Les sardines furent toutes capturées au filet tournant. Lorsque celui-ci est ramené le long du bord il forme une poche ou le poisson est rassemblé et où il est facile d'en prélever au moyen d'une épuisette. Les sardines sont ainsi transférées du filet dans un bac sur le pont du bateau. L'eau du bac doit être renouvelée par une pompe.

Les sardines sont ensuite prélevées une à une et placées dans un sabot correspondant à la taille des poissons marqués. Un jeu de plusieurs sabots est nécessaire si la population capturée présente diverses tailles modales.

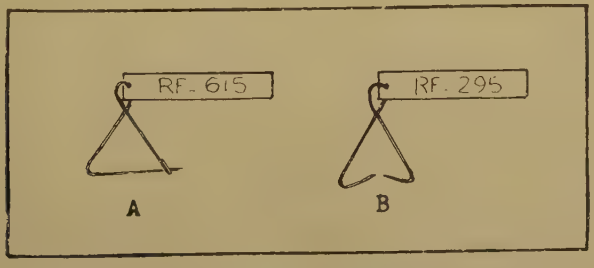


Figure 2. Les deux types de marques utilisées (A et B).

Le rôle du sabot est de maintenir la sardine immobile dans un peu d'eau pendant l'opération du marquage proprement dit et de la manipuler sans avoir à la toucher. Ce sabot est en laiton, fermé à l'extrémité où l'on place la tête de la sardine puis ouvert de chaque côté par une encoche au niveau de la partie antérieure du dos pour permettre la fixation de la marque. Une lame accessoire sur un des côtés du sabot sert à le fixer sur un support ou sur un des côtés du bac ce qui libère les deux mains de l'opérateur.

La sardine étant marquée on la délivre en plongeant le sabot dans un seau d'eau ou directement dans la mer. Les poissons peuvent être ainsi relâchés par petits groupes ou un à un.

Si l'opération est faite rapidement et la fixation de l'agrafe effectuée sans déchirer les chairs du poisson la sardine ne semble que peu ou pas en souffrir et elle s'éloigne ou plonge vivement dès qu'elle est remise à l'eau.

Au cours de cette expérience la marque du type B ne fut utilisée que sur 61 individus mais nous pensons l'essayer à l'avenir sur une plus grande échelle.

Au moment de la capture du matériel un lot de sardine est prélevé et examiné au laboratoire selon les techniques courantes ce qui permet de déterminer la taille modale, l'âge, et la moyenne vertébrale de la population à laquelle appartiennent les poissons marqués.

Nous espérons que ces données et un nombre suffisant de recaptures nous permettront, par de nouveaux marquages, de préciser les déplacements de la sardine du Golfe de Gascogne.

# Ichthyométrie des Thonidés.

## De l'emploi d'une technique internationale.

Par

**Jean le Gall.**

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### Caractères Métriques.

La Conférence des Experts du Conseil International pour l'Exploration de la Mer et de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée, réunie à Madrid en Mai 1932, examinant les méthodes scientifiques et techniques à appliquer à l'étude des poissons de la famille des Thonidés, et passant en revue les caractères ichthyométriques pouvant être retenus pour cette étude, devait constater que, dans les conditions difficiles dans lesquelles les mensurations doivent être faites, ces mesures ne pouvaient pas toujours être prises suivant des méthodes répondant à toutes les exigences scientifiques et qu'elles devaient correspondre à certaines qualités de rapidité et d'exécution pour qu'elles arrivent à porter sur un grand nombre d'échantillons. (Rapp. et Proc. Verb. des Réunions C.I.P.E.S.M. — Vol. VII, N.S. Paris Déc. 1932 pp. 57).

Dans cet esprit, la Conférence groupait les mesures applicables à l'ichthyométrie des Thonidés en trois groupes :

1. Mesures recommandées ayant été déjà essayées avec des résultats publiés;
2. Mesures également recommandées et d'exécution facile;
3. Autres mesures importantes.

**1. Premier groupe.**

— De l'origine au centre de la fourche caudale (longueur du corps). $L_5$.
— De l'origine au bord antérieur de l'oeil (distance préorbitaire). $L_1$.
— De l'origine au bord postérieur de l'oeil. $L_2$.
— De l'origine au point le plus éloigné du bord libre de l'opercule (longueur de la tête). $L_3$.
— De l'origine au point supérieur de l'origine de la pectorale. $L_4$.
— De l'origine à la base du premier rayon de la première dorsale. $L_6$.

— De l'origine à la base du premier rayon de la deuxième dorsale. $L_7$.
— De l'origine à la base du premier rayon de la ventrale. $L_8$.
— De l'origine au bord postérieur de l'anus. $L_9$.
— Longueur de la pectorale. $L_{12}$.
— Hauteur du corps au niveau du 1er rayon de la lère dorsale. $L_{10}$.
— Diamètre interorbitaire. $L_{13}$.

**2. Deuxième groupe.**

— De l'origine au point le plus éloigné du bord du préopercule.
— Hauteur du corps au niveau de l'anus.
— Longueur de la plus grande section transversale des carènes latérales.
— Diamètre interaxillaire.
— Distance de la symphyse intermaxillaire à l'extrémité de la mâchoire supérieure.
— Distance de la symphyse mandibulaire à la commissure buccale.
— Hauteur de la première dorsale (premier et deuxième rayons).
— Hauteur de la deuxième dorsale.
— Hauteur de l'anale.
— Hauteur de chaque lobe de la caudale.

**3. Troisième groupe.**

— Formule des rayons des nageoires, y compris les pinnules.
— Formule des rayons branchiostèges.
— Formule des branchiospines.
— Plus grand diamètre du globe oculaire énucléé.

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L'expérience ayant montré que la valeur de certains de ces caractères était très discutable, les observateurs français les éliminèrent pour ne retenir que :

**(a) Caractères métriques** (distances mesurées entre perpendiculaires).
— Longueur totale, mesurée de la symphyse maxillaire au milieu de la ligne joignant les pointes de la caudale : (L.T.).
— Distance préorbitaire, mesurée de l'origine précitée au bord antérieur de l'oeil : (m).
— Distance postorbitaire, mesurée de l'origine précitée au bord postérieur de l'oeil : (m+o).
— Longueur de la tête, mesurée de l'origine à l'extrémité postérieure de l'opercule : (L. cpl.).
— Longueur préventrale, mesurée de l'origine à la base du premier rayon de la nageoire ventrale : (V).
— Longueur prédorsale, mesurée de l'origine à la base du premier rayon épineux de la première nageoire dorsale : ($D_1$).
— Longueur mesurée de l'origine à la base du premier rayon de la deuxième dorsale : ($D_2$).

— Longueur préanale, mesurée de l'origine à la base du premier rayon de l'anale : (A).
— Périmètre thoracique maximum, mesuré au niveau du milieu de la première dorsale : (H).
— Intervalle séparant (à l'état frais) les deux extrémités de la caudale en extension normale.
Toutes ces distances étant mesurées entre perpendiculaires.

**(b) Caractères numériques**

— Moyenne vertébrale.
— Formule des différentes nageoires.

Cependant, aux Etats-Unis, Godsil et Byers (1944), Schaefer (1948), puis John C. Marr et Milner B. Schaefer (1949), utilisaient dans leurs recherches sur les Thonidés d'autres caractères, définis par ces deux derniers auteurs dans une étude : "Definitions of body dimensions used in describing tunas."[1])

L'examen comparatif de ces caractères avec ceux déjà employés par les travailleurs européens a conduit les Experts du Conseil International pour l'Exploration de la Mer, réunis à Tunis en 1949, à réviser, après une nouvelle expérience de 17 ans, leurs recommandations antérieures au sujet de ces caractères, en ne retenant que les plus simples, faciles à évaluer sans ambiguité et susceptibles d'être utilisés pour l'étude ichthyométrique de *tous* les thonidés. Ils adoptèrent, en même temps, dans le but d'uniformiser les méthodes de travail, certains caractères préconisés par les techniciens américains; puis, de prendre comme origine, dans la plupart des mensurations : l'extrémité antérieure de la symphyse intermaxillaire (le bout du museau), ce choix n'apportant pas de variations importantes dans les mesures suivant la position ouverte ou fermée de la bouche.

Ils décidèrent, en outre, que toutes les mesures seraient prises entre perpendiculaires, de l'origine au point considéré.

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Pour éviter qu'une confusion inévitable se produise dans le choix des techniques biométriques à employer pour l'étude des Thonidés, il nous a paru utile de rassembler dans un tableau, avec leurs symboles correspondants, les caractères définitivement recommandés pour cette étude, de façon que la méthode de travail étant uniformisée dans tous les services scientifiques de recherches de biologie marine, une comparaison et une interprétation faciles des observations puissent être faites sans ambiguité.

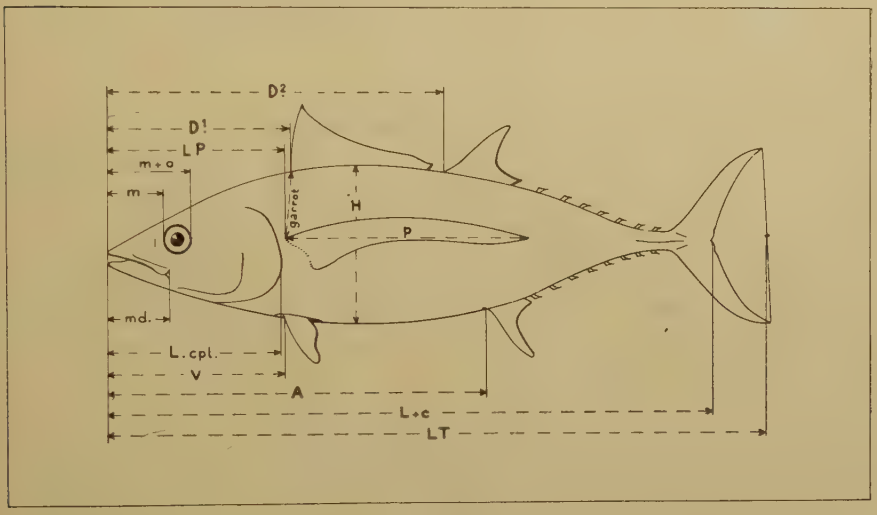
[1]) U. S. Dept. Int., Fish and Wildlife Serv., Fish. Bull., 47, pp. 241—4, Washington, 1949.

**1. Premier Groupe.**

| | Symboles | |
|---|---|---|
| | France | Cadix Malaga Tunis |
| *Longueur totale* — Distance mesurée du bout du museau, défini comme origine, au bord cartilagineux de l'échancrure qui marque le milieu de la fourche caudale, (le bord cartilagineux de la fourche caudale est trouvé en déprimant par une pression légère le rebord charnu de cette nageoire sur le bord cartilagineux de la fourche caudale). | L. c. | $L_5$ |
| *Observation* — Dans leurs travaux antérieurs, les observateurs français ont pris comme longueur totale L.T. : la longueur "hors tout", mesurée du bout du museau au milieu de la ligne joignant les pointes de la caudale. De nombreuses mesures ont montré que L.T. = L. c. × 1.07. | L. T. | |
| *Longueur céphalique* — Distance mesurée du bout du museau au rebord postérieur le plus éloigné du subopercule (en déprimant le rebord charnu s'étendant légèrement en arrière). | L. cpl. | $L_3$ |
| *Distance préorbitaire,* mesurée de l'origine précitée au bord antérieur de l'orbite. | m | $L_1$ |
| *Distance postorbitaire,* mesurée de l'origine précitée au bord postérieur de l'orbite. | m + o | $L_2$ |
| *Diamètre de l'orbite :* O = (m+o) — m = $L_2$—$L_1$. | O | $L_2$—$L_1$ |
| *Espace interorbitaire :* mesuré au compas à pointes courbes, ou entre perpendiculaires, sur la face postérieure du crâne, entre les bords supérieurs des deux orbites. | E. O. | $L_{13}$ |
| *Longueur prédorsale,* mesurée de l'origine à l'insertion du premier rayon de la première nageoire dorsale verticalement redressé. | $D_1$ | $L_6$ |
| *Longueur à l'insertion de la 2ème dorsale,* mesurée de l'origine à l'insertion du premier rayon de la deuxième dorsale, définie par l'intersection du bord antérieur de la deuxième dorsale redressée avec la ligne médiane dorsale : (contour du dos). | $D_2$ | $L_7$ |
| *Longueur préventrale,* mesurée de l'origine à la base du premier rayon de la nageoire ventrale redressée. | V | $L_8$ |
| *Longueur préanale,* mesurée de l'origine à la base du premier rayon de la nageoire anale. | A | $L_9$ |
| *Longueur préscapulaire,* mesurée de l'origine à l'insertion antérieure de la nageoire pectorale. | L. P. | $L_4$ |
| *Longueur de la pectorale,* mesurée de l'insertion antérieure à son extrémité distale. | p | $L_{12}$ |
| *Hauteur du corps :* Plus grande distance entre le contour dorsal et le contour ventral, mesurée au niveau du rayon *médian* de la nageoire dorsale, celle-ci étant déprimée dans son sillon. | H | $L_{10}$ |

**2. Deuxième Groupe**

| | Symboles | |
|---|---|---|
| | France | Cadix Malaga Tunis |
| *Hauteur antérieure du dos* — Distance mesurée entre perpendiculaires de l'insertion de la nageoire pectorale à l'insertion de la première nageoire dorsale ("Garrot"). | Gar. | |
| *Longueur du maxillaire* mesurée du bout du museau à l'extrémité postérieure du maxillaire. | Mx | $L_{17}$ |
| Hauteur maximum du pédoncule caudal. | | |
| Hauteur minimum du pédoncule caudal. | | |




## I. Caractères Métriques.

D'une façon générale, toutes les mensurations seront faites sur le côté gauche du poisson (ventre en bas, la tête de l'animal étant située à gauche de l'observateur), à partir du point pris comme origine, situé au bout du museau : à l'extrémité antérieure de la mâchoire (symphyse maxillaire).

## II. Caractères Numériques.

Formule des Rayons des nageoires :

*Nombre de rayons de la première dorsale.*

Nombre des rayons discernables, la nageoire dressée. (Le rayon postérieur est parfois sous-cutané; dans ce cas, il ne doit pas être compté).

*Nombre de rayons de la deuxième dorsale.*

Nombre de rayons discernables, la nageoire dressée.

Etant données les difficultés pour différencier les pinnules dorsales

antérieures des rayons postérieurs de la 2ème dorsale, les Experts réunis à Cadix avaient décidé d'intégrer le nombre de pinnules dorsales dans le nombre des rayons de la 2ème dorsale, en représentant ce dernier nombre en chiffres arabes, le nombre de pinnules étant représenté en chiffres romains.

Ex. : $Rd^2 = 22 = 14 + VIII$.

Cette façon d'opérer paraît être la meilleure.

*Nombre de rayons de la nageoire anale.*

Même observation que pour les rayons de la deuxième dorsale :

R. : An = 22 = 14 + VIII.

*Nombre de rayons de la nageoire pectorale.*
*Nombre de rayons de la nageoire ventrale.*

Ces deux caractères ont été définitivement écartés.

*Nombre de branchiospines,* visibles ou senties avec une aiguille montée, comptées sur le bord antérieur du 1er arc branchial (arc antérieur) sur le côté gauche de la tête du poisson.

Le nombre de branchiospines sur chacune des branches de l'arc est exprimé séparément. Ex. : branche supérieure = 10 branchiospines; branche inférieure = 20 branchiospines. Formule : 10 + 20 = 30 brs.

## Indices Biométriques.

Les différentes proportions du corps, calculées d'après les données ichthyométriques ainsi définies, sont établies sous la forme d'*indices biométriques* en les rapportant à une unité déterminée : généralement la longueur totale du poisson.

**Indices recommandés:**

1. Hauteur du corps en fonction de la longueur totale ..... $Hi = \frac{100\ H}{Lc} = \frac{100\ L_{10}}{L_5}$
2. Longueur de la tête —d°— $T(i) = \frac{100\ Lcpl}{Lc} = \frac{100\ L_3}{L_5}$
3. Longueur prédorsale —d°— $D^1i = \frac{100\ Di}{Lc} = \frac{100\ L_6}{L_5}$
4. Longueur à la 2ème dorsale en fonction de la longueur totale ..... $D^2i = \frac{100\ D_2}{Lc} = \frac{100\ L_7}{L_5}$
5. Longueur préventrale —d°— $Vi = \frac{100\ V}{Lc} = \frac{100\ L_8}{L_5}$
6. Longueur préanale —d°— $Ai = \frac{100\ A}{Lc} = \frac{100\ L_9}{L_5}$

7. Longueur préscapulaire en fonction de la longueur totale ..... $Pi = \frac{100\ Lp}{Lc} = \frac{100\ L_4}{L_5}$

8. Longueur pectorale —d°— $pi = \frac{100\ p}{Lc} = \frac{100\ L_{12}}{L_5}$

9. Diamètre de l'oeil en fonction de la *longueur céphalique* ..... $Oi = \frac{100\ O}{Lcpl} = \frac{100\ L_{12}}{L_3}$

10. Distance interorbitaire en fonction de la longueur céphalique ..... $\frac{100\ Eo}{Lcpl} = \frac{100\ L_{13}}{L_3}$

Cette liste des caractères morphologiques et des indices ne peut être considérée comme limitative.

# Environmental Changes in Herring Behaviour: a Theory of Light Avoidance, as Suggested by Echo-Sounding Observations in the North Sea.

By

**Ronald Balls.**

## Introduction.

During some ten years of using the echo-sounder as an aid to drift-net fishing I have been much concerned about the behaviour of herring. Watching a continuously sounding echometer is like looking at the sea bottom through the water beneath you; and since fish or any other objects suspended in that water will show echoes, the detection of herring in the sea would seem to be a simple matter. But this is not so. For most of the time, especially in daylight, the herring are very difficult to find.

If a herring shoal is echoed, quite obviously herring are present in that area. But good catches are often obtained at night where careful searching during the day has yielded no fish echoes of any kind. So it is safe to say that the absence of echoes is not proof of the absence of herring.

What, then, are the herring doing when they will not show echoes? Why is it that they can be found at some times and not at others? When it is realized that a drifter returning empty from the fishing grounds is like a hunter coming home without meat, it will be understood how the solution of this problem is of first importance to me as a fishing skipper.

Up to the present we have known very little about the behaviour of this important food fish. It is called pelagic, apparently in the belief that most of its life is spent away from the bed of the sea.

Certainly the herring come to the surface at night. They are caught in great quantities by drift-nets, which work to a depth of about 10 fathoms, during the summer and autumn fisheries of the North Sea. But they are also caught in perhaps greater numbers by trawling on the sea bed. And as the trawl catches have shown a diurnal rhythm, not

only in the quantity but in the size of the constituent individuals, we could take this to mean an up-and-down movement governed by night and day.

Yet not everyone would accept this view. Some are of opinion that trawl and drift herring are quite independent races; that the catching of one kind has no effect upon the other. This idea is based upon the fact that in areas like the Fladen Ground and Dogger Bank where trawling is regularly most successful, the surface drift-net is least so. There are fishermen who are emphatic that the herring of these trawling grounds never come to the surface. Others declare that the drift herring do not go to the bottom. These beliefs, with others of questionable validity, show the sketchy nature of our knowledge of a subject which, considering the importance of the fisheries and the value of behaviour details to catching efficiency, is surely worthy of some study.

There is, so far as I can see, no animal on land, unless it be the lemming, to compare with the herring in the sea. The herring is prolific, with a wide distribution in temperate and northern waters; it is preyed upon from birth by many sea birds, all the larger fishes, and some whales — and even before birth, when its demersal eggs form the sole diet of the "spawny" haddock; and it is withal a mercurial creature whose highly sensitive herding instinct transcends that of flocking birds.

It is notable that of our main food fishes the herring stock alone has shown no serious sign of depletion through fishing. Natural mortality in the case of this fish is obviously of much greater importance than the effect of the drift-net or trawl.

We must remember this point. For the knowledge that the predominant urge in the herring is the instinct for survival — to avoid being eaten — is the key to much that is otherwise inexplicable in its behaviour.

Einar Lea and W. C. Hodgson have shown that herring scales with their yearly growth-zones can be used as birth certificates. The latter (1) is now regularly forecasting the composition of the East Anglian shoals, estimating the percentage of each year-class from the systematic sampling of the previous fishing. A. C. Hardy (2) has found associations between herring catches and the abundance of certain plankton forms; positive with *Calanus* and other copepods, and negative with dense plant concentrations. And it is known that their feeding ceases with the ripening of the sex glands. The stomachs of migrating pre-spawners, as at East Anglia, are generally empty.

But about the actual manner of their shoaling, the way of the herring in the sea, there is much to be explained. Consider, for instance, the "swim". What is this particular phase in the herring's behaviour without which the fleets of drift-nets, with their waiting wall of meshes, would probably be useless? To quote Graham (3), "to define 'swim':— Something happens limited in time and space, the result of which is that herring are caught in the nets, in numbers from say five thousand to a quarter of a million per fleet of nets; this phenomenon is called a swim of herring."

Sometimes this swim stage is of very short duration; at other times it will last for hours. Other differences in behaviour are noticeable from one fishing to another. The herring at East Anglia do not conform to the same ecological pattern as those of the summer fishings. And in some Norwegian waters yet another system of shoaling is evident.

Now in the waters from the English Channel to Norway we have to consider depths varying from ten to over one hundred fathoms. And this environmental gradient, crossing as it must the fairly uniform level of light penetration in the sea, forms the basis of my explanation of fundamental changes in the behaviour of herring shoals.

We can divide the depth range of the fisheries into three regions:—

1. The middle zone, with depths between 30 and 70 fathoms, which takes in the summer herring from Flamborough Head to north-east Scotland. Here the herring rise from the bottom in compact groups and spread out near the surface, a precise type of behaviour which can best be called *three stage*.
2. East Anglia, or the shallow zone, with depths of 30 fathoms or less, and much stronger tidal streams, where we see a more intense action which cannot be divided into more than *two stages*.
3. The deeper water from 70 to over 100 fathoms at the Shetland and Norwegian grounds, where is what may be called *one-stage* behaviour — keeping in large masses which move but do not greatly alter formation. The behaviour noticeably changes again to two or three stage on the spawning banks of 50 fathoms or less.

I do not wish to imply that all the herring in any one region hold to a rigid code of action. The changing physiological states of the fish, i.e., feeding, pre-spawning, and spawning, would in themselves produce somewhat different behaviour, whatever the external conditions. And behaviour undoubtedly changes with the age of the herring too. But the general patterns of shoaling observed in the three regions seem to be definitely linked with the different depths of water.

The general conclusion is that the herring instinctively require a modicum of darkness to be comfortable, and this condition varies with the depth of water, causing variation in behaviour.

## Three-Stage Behaviour.

The middle depth-zone of between 30 and 70 fathoms contains all the main summer herring fisheries. The Shetland grounds include greater depths and are therefore best considered with the deep water region. All my summer observations have been made in the middle depths, and results have been so consistent that I feel this to be my safest ground to begin with.

The type of behaviour generally found in this region is, I believe, most important to our fishermen and researchers, not only in relation to the systematic location of herring shoals by echo-sounder, which may develop in the future, but because it is so very different from the previously accepted ideas of drifter men who naturally think in terms

of their long fleets of nets. Moreover it seems to have a definite basic structure similar to that seen in the evolutions of starlings, or even possibly to approach such rigid behaviour codes as exemplified in the skein formation of geese in flight.

Here are the three main facts which have come from continuous summer observations in this depth region:—

1. Herring can very rarely, if ever, be seen by echo during the hours of greatest light intensity, even when they are known to be in the area.

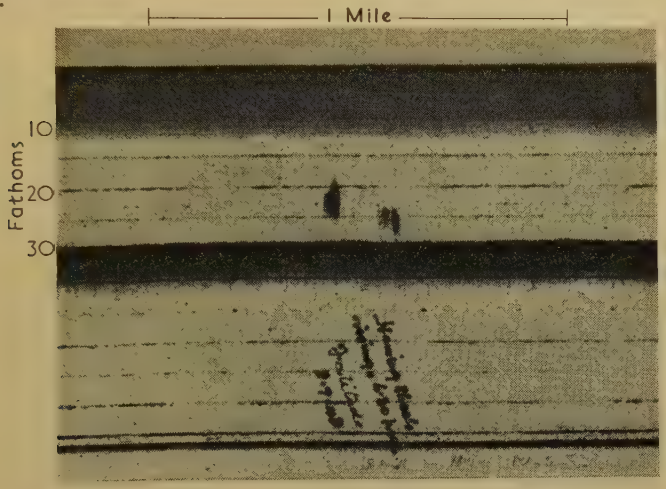



Plate 1a. Record of herring shoals. Ship moving at 8 knots, 60 soundings per minute. Such shoals and smaller ones are often seen during summer evenings. Depth 30 fathoms.

2. Herring can be echoed during the evening, always in comparatively small groups, at various depths from the bottom to about ten fathoms. These shoals are roughly spherical, though not always so, and may vary from 20 to 150 feet in diameter. That the density of herring in the shoals will vary also is shown by different kinds of echo.
3. When drift-nets are shot in the vicinity of one or more of these shoals, catches of herring will be obtained at some time during darkness, the herring generally regularly placed along the fleet of nets. Echoes of herring may be seen during darkness, but a good catch does not depend on these echoes being seen.[1])

These facts suggest three distinct stages in behaviour, namely:—

(1) The herring are spread at the bottom during high day.
(2) They are rising in groups during the evening.
(3) They must spread at, or near, the surface at some time during darkness.

[1]) For further details, see "Fish on the Spotline" (4).

Plates 1a and 1b show records of typical herring shoals that can be seen during the evening in summer. In my experience, apart from very rare exceptions, herring are not seen in much larger shoals in this depth region.

Before 1938 I had listed 69 nights of shooting drift-nets when one or more such shoals had been seen; the average catch was 26 crans against an average of 8 crans for shots where no echoes had been seen. We were using a Marconi Echometer type 424 then, with a visual peaking light system, but since the war with a Seagraph recorder our results

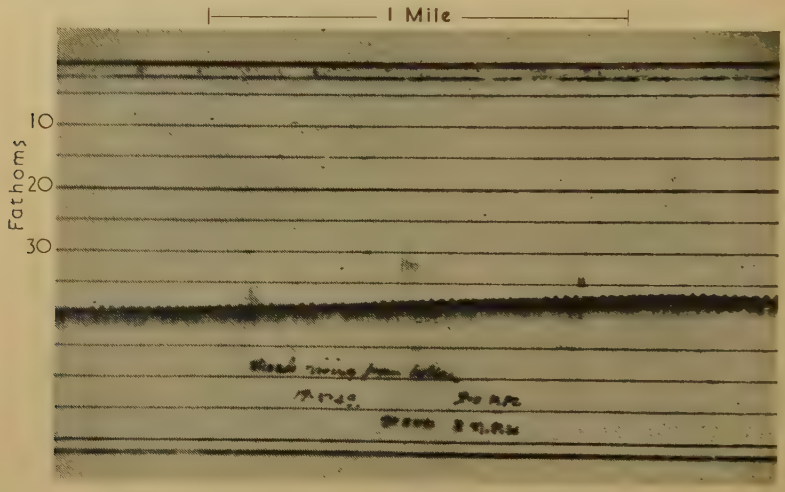



Plate 1b. Record of small shoals rising in the evening. Depth 40 to 37 fathoms.

have been very much the same. Indeed after the first difficult period in 1933 — when the absence of echoes in daylight seemed so mysterious and baffling — we never expected larger shoals. We were quite glad when we saw a small one because it told us we were on herring; and the resulting catches proved it. Our biggest shot from shooting on only one shoal was 40 crans. But the average catch where more than one shoal was seen in the shooting area was 54 crans.

This is significant. The average catch for the nights when more than one shoal was seen is fully twice as great as the average from shooting on a single shoal. The period of searching was of course variable. There were nights when we shot immediately on seeing one shoal. But more frequently we searched about in the adjacent waters before shooting as near as possible to the shoal we had echoed. When a second group was located the choice of shooting position was made easier, and the catch more sure.

I have tried to estimate the number of shoals that would be rising before darkness in a given area, to account for a certain average catch by the boats fishing there, and thus to form some idea of the chance of

locating them with a vertical sounding beam having a spread of 12 to 15 degrees. But this is too difficult. In the first place it is hard to estimate the stock from drift-net catches; in the second it is not certain that all the shoals will be rising at once. The seeing of shoals almost simultaneously at different depths, say at 20 fathoms and at the bottom in 60 fathoms (which occasionally happens), shows that the rise may be spread over an indefinite period of time.

Some considerable difference occurs in the size of the shoals, but there is no evidence that the shoals are larger when the fishing is heaviest. It is probable that *the greater the concentration of herring in the area the greater will be the number of shoals rising there.* But further than that we cannot go.

To illustrate this problem of comparing shoals with catches I will quote briefly the facts of one shot in 1938:[1]) "A big fishing was landed one morning at Shields from grounds 20 to 25 miles E. to E.×N. While running off again that afternoon midwater echoes were seen at 14, 15, and 16 miles — that is, three separate groups of herring, none more than 5 or 6 soundings wide, at intervals of a mile. On an E. ½ N. course this was in 51 and 50 fathoms.

"At 17 miles the ship was stopped and lay to the moderate westerly wind while the rest of the fleet steamed by. An hour or so later she was steamed back W. ½ S. for 4 miles, but though the spotline was watched carefully *nothing at all* was seen. The nets were then shot E.×N., finishing in 50 fathoms, with a few boats just visible to the eastward.

"At midnight no herring were in the nets, so hauling was postponed until 2·0 a. m. The watch, switching on the echometer at intervals, saw good surface echoes at about one o'clock. The catch was 104 crans in a full length swim.

"The fishing further out was almost blank, excepting two boats with good shots from 20 miles E.N.E. (on the north-west edge of the main fleet)."

In this account of only one night's fishing there is material for a volume of conjecture and discussion. For one thing there is an obvious move of the whole herring concentration some 5 miles or more to the westward. Then there is the seeing of three small shoals of herring while steaming off, but none when going back over the ground. And more puzzling still is the fact that although groups of herring were in midwater (actually at 15 to 18 fathoms) long before the close, no herring went into the nets until after 1·0 a. m., after which a fine regular swim was hauled.

Now I am assuming a three-stage behaviour pattern where only one stage, that of rising in groups during the evening, is actually shown by the echo-sounder. But we have the evidence of the drift-net catches to prove the third or swim stage.

As a general rule the swim in summer occurs at some time during the darkness, though occasionally at dusk or break of day. It may be

1) Quoted from "Fish on the Spotline".

of long or short duration according to the physiological state of the fish, *but it happens only once in the 24 hours.* The result is a catch of varying density in the nets. Good catches are often spread regularly along the 1½ miles of gear, which could not happen if the herring remained in the compact groups seen earlier in the evening.

Of the first stage, or spread at the bottom, I have no proof, but there is considerable evidence suggesting this. In one case ("Violet and Rose", 1938) we were lying in noon sunshine in 70 fathoms on the Fladen Ground where several boats had that morning hauled good catches. Although we had been trying the sounder no fish echoes had been seen. But when a trawler towed her gear close past us a fine shoal appeared for some minutes, the echoes showing them to be nearly 10 fathoms thick, and just clear of the bottom. Disturbed by the passing

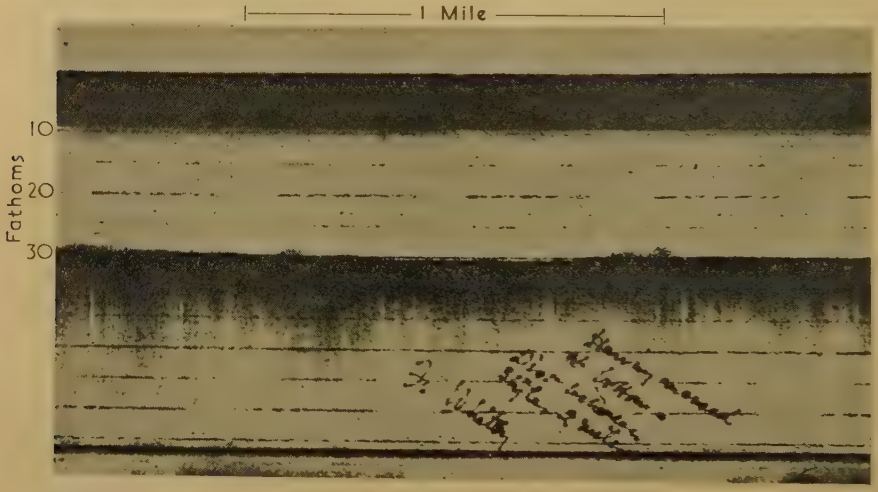



Plate 2. Herring massed at the sea bed. Ship steaming at 8 knots; 60 soundings per minute. Depth 30 fathoms.

of the trawl the fish had apparently massed and risen slightly, just as a field of feeding birds might rise and flock when startled. We shot there that night and got 70 crans.

Other evidence of herring being at the sea bed comes from trawlers. In calm, late summer weather trawler reports of herring are liable to be misleading. The herring may be there and yet not be caught by surface drift-nets. But there are many cases in early summer of drifters being led to good catches by the Shields trawlers reporting the presence of herring among their whitefish hauls.

It is difficult to see herring at the bed of the sea, and impossible when they are thinly spread, as I believe them often to be. But the next best thing is the seeing of echoes like those in Plate 2 from herring masses at the sea bed. After innumerable experiences of sounding without echo

results in daylight on grounds where herrings were known to be abundant I am convinced that in stage one the fish are almost flat on the bottom.

As we know that the herring are contained in their element by the surface and the sea bed we have only to assume a strong enough force pressing them up and down to explain their spreading at each of these limiting planes. And though we may be far too ignorant of the many factors that influence herring to define their behaviour in precise terms of stimulus and response, it is natural to look for the causes of the pattern that is seen.

In considering herring behaviour, as well as that of many other organisms, we cannot ignore the influence of light. It is well known that this governs the up-and-down movements of many plankton forms. That drift fishermen realize its importance is shown by their methods of working. I remember one very keen skipper I sailed with long ago walking the deck after we had shot on good herring signs, rubbing his hands and saying, "Make haste and get dark!" After the close of day fishermen heave up the nets expecting to see herring, but they do not catch them in the high noon day — except at East Anglia — which would agree with the herring being down.

Another noticeable feature agreeing with the idea of light avoidance in herring is that there is much variation in the time at which the rise takes place. On a dull, roughish evening herring groups may be seen at 6 or 7 p.m., but they are seldom seen so early in bright or calm weather.

It is reasonable then to suppose that the action of the herring in stage one is entirely photophobic; that in depths of 70 fathoms or less the desire to avoid the light drives them so close to the bottom that they will not show echoes.

In the seeing of herring on the sea bed during the evening we have evidence that the fish are at the bottom during high day. The herring is not a bottom-living fish, and the beginning of its rise from the sea bed coincides with the relaxing of the force that has been keeping it there. The fact that they gather into compact shoals during the rise is not so easily explained. It is apparent that with the diminishing of the light influence some other factor becomes the most important and causes polarity, or the close shoaling in the intermediate waters.

I believe that the explanation of this three-stage behaviour will best come from a study of the second, or rising group stage. In midwater apparently this shoaling is the natural disposition of the herring. Why should this be? The obvious answer, that shoaling facilitates reproduction, does not wholly satisfy because the close formation can be observed in all physiological states of the fish — and at all ages. Spawning certainly does intensify the social action; but it seems possible that shoaling in herring is a primary instinct that has been built to a large extent upon the urge for survival.

To avoid being eaten, to eat, and to reproduce are three fundamental needs common to small wild animals. In the sea it is probable that the first of these three has most effect on herring behaviour. The fish must

eat of course, and at maturity it must spawn, but it can do neither without remaining outside the belly of one of its many hunters. So that while the feeding and reproductive urges act only at different particular times or periods of development, the need for survival is always present, always influencing action.

Safety in numbers appears to be the first precept in herring behaviour. We cannot watch the adults, but this can be seen very easily in the whitebait. They are always in shoals; one never sees a single whitebait — indeed the term itself needs no singular form. In many hours of watching the movements of these young herring the thing most real about them, and yet most indefinable to me, was their affinity and attraction for each other.

Their action when undisturbed seems to consist of short forward dashes between stops to twist or turn up, down, or sideways, in a ratio of 1 or 2 parts swim to one of rest — an action very similar to the suspensory movements of copepods etc. Where there is a current the fish are usually stemming it, and they are generally about half their length apart.

But when they are disturbed this playful action becomes something quite different. The swim is forceful, away from danger, with the formation much closer than usual; and most remarkable is the whiplash action of any rearguards that are threatened with isolation. The fish seem to be tied together. Their action is intensely expressive of either (a) an instinctive fear of the naked space, or (b) an instinctive need to maintain contact with the main shoal.

One cannot watch this amazingly concerted action — this highly concentrated form of "devil take the hindmost" — without realizing that it is a product of the instinct for survival. Contact with the shoal means safety; to be alone means elimination. And since the tiny fish cannot be presumed to be conscious of this the connexion must be a physical one. We may call it the magnetism of the shoal.

Although we know that behaviour observed in the young cannot always be attributed to their adult forms there is without doubt some vital power of attraction in herring.

Let us suppose that the herring are joined by a sensory connexion acting like invisible strings, which compels them to dress to a certain formation, a precise distance apart that is necessary to satisfy their particular physiological condition. Feeding shoals could be somewhat sparsely connected; spawners and disturbed shoals, more close and tensed. In daylight the fish could be spread at the bottom in a flat formation and still maintain the lateral contact, almost like soldiers in single file. Such a disposition would be imposed upon them by the sea bottom preventing any further downward movement away from the light at high day.

With the diminishing of the light the evening rise, which is almost certainly not an upward swim, but more probably a playful whitebait-like movement in the general migratory direction, an action punctuated by upward flirting motions of individuals, whose cumulative effect

would be the slow rise of the whole shoal — this rise, then, would begin with a kind of multiple forming of fours. As one or two herring lifted, others would close in below and around them to retain the formation or grouping most suitable to them.

Once clear of the sea bed the sensory attachment would, like the action of surface tension, ensure compactness of the shoal; the pull of the inner fish would be neutral because of others all around, but the outside members would be pulled only inwards.

Thus we can see that the evening rise, when the herring can be readily indicated by the echo-sounder, is simply the reforming of shoals which have been pressed flat by negative phototaxis, so flat, in my belief, that no trace of them can be seen.

The acceptance of this three-stage behaviour theory must of course recognize the existence of a fourth stage in which the herring return to the bottom. I have purposely omitted mention of this because I have no evidence of how it takes place. I have several graphs of herring which are apparently settling down in shoal formation in the same way as they rise, but these were obtained at Whitby on spawning herring whose behaviour may not be typical of that of non-spawners in off-shore waters. For one thing the surface spread is far less pronounced in spawning shoals.

It seems that the swim, which may be long drawn out and playful in young and feeding herring, and of short duration in older fish (especially after the month of June), is the culmination of the upward rise; but whether the herring go down immediately after, or whether they take the bottom again only when daylight drives them down it is impossible to say. Further discussion of this will only introduce needless complications.

It will be seen, then, that this summer behaviour in the medium depth-zone has a measured rhythm and pattern that is closely linked with night and day. A feasible explanation of it can be sustained by the assumption of only three main stimuli. These are the downward driving force which we have in light, a lifting influence which may or may not be the herrings' need to maintain an optimum light condition, and the polarizing influence which I have suggested is the sensory attachment or inborn shoaling instinct.

Finally, it is a phenomenon that can be observed at almost any time in summer. I have experienced it for many years in depths between 30 and 70 fathoms, and it is not noticeable, save as an exception, in the shallow depth-zone, as the following discussion of the East Anglian fishing will show.

## Intense Behaviour in the Shallow Zone.

We can take as typical of this zone the East Anglian grounds where the fishery takes place in from 10 to 30 fathoms. Another difference here is that the tidal streams are much stronger than in the deeper waters further north.

In ten years experience — 7 before and 3 since the war — I was not able to use the echometer as a reliable guide to drift-net fishing in this depth-zone. We could echo the herring, though not very often, but the tempo of the fishing is faster, and the herring behaviour different. For this reason I have stated (4) that echo fishing is not practicable in a drifter in East Anglia.

The main reason for this is that the echo-sounder cannot be used in a negative way. Large catches may be obtained where no herring echoes are seen, which as we have seen is also true in summer.

I mention this because during the 1948 season experiments by Ministry of Fisheries researchers resulted in herring being echoed easily and frequently in October. Not being at sea last autumn I had no experience of this. I am inclined to say — since that is contrary to my previous findings — that the frequent echoes were due to the prolific shoals of very young herring, whose behaviour differs from that of older fish, to which subject I shall return later. We are not concerned here with the value of the echo-sounder as an aid to fishing, but only with its evidence on herring behaviour. In passing, however, I may say that of 11 drifter echographs (taken while shooting) with an average catch of 75 crans, which I obtained from skippers, not one had any signs of herring echoes; I can quote my friend Skipper L. K e a b l e, as saying, "Yes, we could see the herring very well, but we couldn't catch them".

There are several ways in which the East Anglian herring behave differently from those of the medium depth-zone. In the first place, the regular effect of light and darkness is broken and dominated by the tidal influence. More herring are caught at night, but there will be separate swims at, say, the close of day, midnight, and perhaps daybreak, according to the times of slack water.

Secondly, the herring are strongly affected by the moon. H o d g s o n and S a v a g e (5) have shown the lunar influence on the East Anglian landings, where definite peaks invariably coincide with the October and November full moons.

There is no evidence of greater landings at new moon, but even then the lunar influence is shown in quite a different way. Besides intensifying the swims at full moon, it will at November new moon sometimes reverse completely the rhythm of night and day. Thus in some seasons we see the unique phenomenon of the swim occurring only in the daytime. At sunrise, midday, or mid-afternoon according to the tides, the season's heaviest swims will take place, while throughout the night the nets will hang quite empty.

At such times the herring, though not spawning, are undoubtedly actuated by some very powerful sexual influence. Their behaviour has the frenzy of swarming bees. Instances are known of quite large bodies of herring being forced some feet clear of the water in these spurts of daylight activity, which often mean net losses through the weight of fish. This excitement is in some way connected with the moon. It seems to be the complement or opposite pole of the lunar-tidal rhythm which

can be seen competing with that of night and day. No peak is shown in the landings, as at full moon, because the daylight swims are most intense and localized, and they occur when many fleets of nets are not in the water.

The main East Anglian behaviour difference, i.e., that the swim is strongly correlative with the change of tide, or slack water as we call it, has as yet no explanation. The fishermen's common knowledge of this often influences their method of working. It also seems that some slacks are more favourable for the swim than others, though opinions may differ about this.

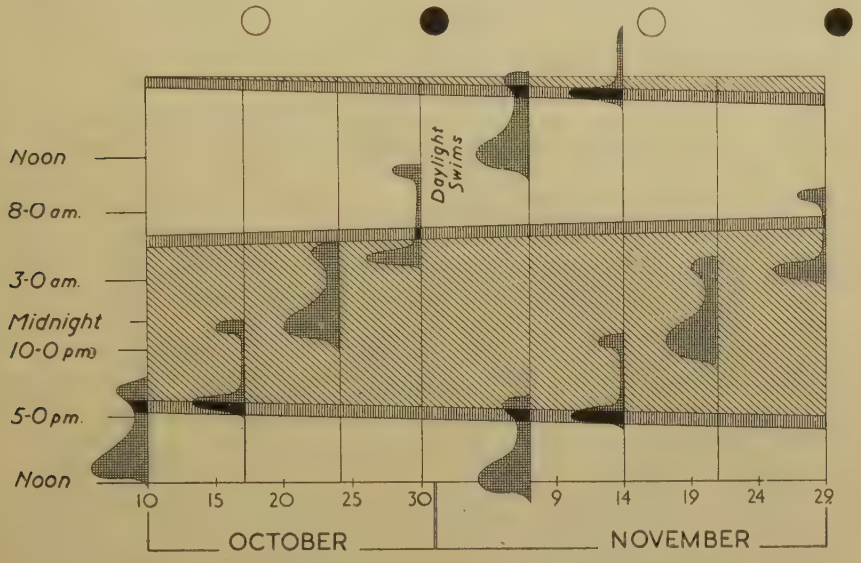



Figure 1. A schematic representation of the probability of a swim according to time of day, tide, and date, in the East Anglian season. Based on fishing experience.

I would go further and say that the connexion of slack water with swim is so close that a change in one produces a change in the other. At spring tides the stream runs faster, and the pause at high and low water is very short. Under these conditions the swim is intense, of short duration. At neap tides, when the stream is dull and the slack period much longer, the behaviour is comparatively relaxed, with the swim of longer duration.

Generally the period of low-water slack and the first run of the flood is the most favourable time for the swim. On weak tides the herring will swim during the flood. Next best is the high-water slack, and the least propitious time of all is when the full ebb is running.

It is difficult to assess the relative importance of the conflicting behaviour factors acting in this zone, but my conception of it is shown in Figure 1, where the tidal, and day and night influences are plotted against the two moons of the 1948 autumn season.

We can see how the seal-like shapes of likely swim times (low-water slack, flood, high-water slack), becoming sharper at springs, move across the darkness and into the day time to produce the daylight swims at the November new moon, or "darks". There are of course two low-water slacks in the 24 hours, but one of these, when the moon is in the east and south quarter, is far more important. When this is considered with the well known fact that the herring usually swim in a south or south-east direction it seems as though the moon is most influential when the spawning migratory impulse is satisfied by the swim towards it.

The area representing night is shown darker at the hours of dusk and daybreak, since these times, the former especially, seem to retain to some extent their influence on behaviour. So that where the favourable tidal periods coincide with these a blacker area is formed, indicating times of almost certain swims.

The brief intensity of some swims can be noted in the following case, which also illustrates the difficulties encountered in echoing East Anglian herring.

[1])"It was on 21. October 1934. The moon was full and herring were plentiful. 'Violet and Rose' shot at noon 14 miles E.S.E. of the South Buoy and drove north with the ebb some 9 or 10 miles to reach the Smith's Knoll watch buoy at the 5·0 p.m. low-water slack. During this time the echometer was watched continuously.

"At the slack water, 5·15 p.m. a heavy swim of herring occurred which lasted only a few minutes, perhaps only seconds. The boats on either side could be seen hauling for the buoy in the closing light; their nets, coming black one minute, were a white sheet of herring at the next.

'Violet and Rose''s nets were full too. The fishing was general over the whole area, the average of more than 100 crans completely glutting the market. But no echoes of any kind were seen."

The point to notice is that while the ship drifted over 10 miles of ground abundant in herring the echometer gave no indication of their presence; in five hours' continuous sounding there was no echo except the normal depth peak. Unless the herring are spread at the bottom like a mat there is no explanation of this. It agrees with summer experience during high day. It disagrees in that there was no sign of the shoaling stage before the swim. The question at once arises, Is it possible for so many herring to be at the bottom, and yet not be thick enough to show echoes?

If the catch on 21. Oct. 1934 is guessed to be $^1/_{400}$ of the total fish in the area, then eight drifters catching 1000 cran (one million fish) in four square miles would make the stock there 400 million herring, or 100 million to the square mile. This would give a square foot of bottom space to every three-and-a-half fish.

Apart from this speculation the foregoing description will show the difference between typical spring tide behaviour at East Anglia and that experienced in the deeper waters further north. The almost

[1]) Taken from "Fish on the Spotline".

leisurely 24-hour rhythm of summer is changed to something much more intense; what is black, grey, and white in northern waters becomes sharply black and white here in the shallow zone. The herring seem to be chained down by some force for long periods, culminating in short bursts of feverish upward activity.

For want of a better description I have called this two-stage behaviour. For varying periods the herring are so disposed that first they are not caught in drift-nets, and second that they are caught. Although there may be some relaxation of this behaviour tension during neap tides I have seen no evidence of the intermediate, or compact group stage which is such a notable feature of the summer pattern.

If there is any value in the evidence of light avoidance so far shown, its effect in the shallow zone would be to hold the fish even more closely to the bottom, since most of these fish can be assumed to have moved in from deeper water on their southward migration. With such a close orientation to the bottom we can explain the relation of slack water to swim. If the herring, with noses down, have been stemming a 2-knot stream some different action would probably be produced by the stopping of the stream alone, apart from any other changes that may occur at the slack water. The rise, or swim on the flood, could be due to the herring's disinclination to turn northward to stem the south-running stream. In the case of daylight swims, we can assume that the slack-water conditions, coupled with the sexual excitement in the fish, produce stimuli which are powerful enough to overcome, temporarily, the influence of even bright sunlight.

Having shown the main behaviour differences seen in the shallow zone, there is another point so far unexplained that should be mentioned. A well known feature in East Anglian herring is what fishermen call high swimming, which usually occurs late in the season. To accommodate this the buoy strops are shortened so that the tops of the nets are at the surface; even then the fish are meshed only in the top yard or so of netting.

Now for this to happen the herring must swim almost vertically to the surface before resuming the migratory direction of swim. This has some resemblance to three-stage behaviour, but again there is no evidence to show whether or not they rise in compact groups or not. The fact that high swims will occur in very close fleets of nets makes the rise in groups seem unlikely.

## Behaviour in the Deep Water Zone.

In Norway the echo-sounder is established as an essential aid to fishing, not only for depth finding as in Britain, but more especially for locating fish. The cod and herring fishermen are extremely "echo conscious", from the fishing master whose work of controlling the fishing is simplified by the sounder, to the youngest member of the crew. Everyone on board the purse seiner that I was in looked for herring echoes as a matter of course, decidedly the "new look" in fishing.

The explanation of this is simple. It is not, as some might suppose, that the Norwegians are so much smarter than us as fishermen, but simply that their methods of working, and the conditions prevailing in their fisheries are much more suitable for successful echo fishing than our own. I should say, rather, than some of our own, for at Whitby in September we have a fishing that is Norwegian in miniature. Here, on a spawning ground roughly about 10 miles by 30, hundreds of ring-netters and drifters nightly locate herring by echo and catch them in plenty. The intense fishing could be much heavier if the market for spawny herring was not so limited.

Norway has herring abundance like this along a 600 miles stretch of coastline, but with this exception, that the water is much deeper. Except for one plateau between Stat and Ålesund the continental slope is very steep, and the 100-fathom line runs close inshore.

In January the large herring fishing takes place from Bergen northward to Ålesund; February sees the heavy shoals of "small" herring, which are a different race, and spawn on the coastal banks from Bergen to Lista, in the south. In favourable years the herring come in to the very rocks, where the shore seines surround them in great quantities. Since they have found markets, and a greater outlet for oil and meal, the Norwegians have developed their catching methods to a remarkable degree. The rise of the purse seine, which can take 2,000 crans at a single shot, is a notable feature. Almost always they find the fish by echo-sounding.

Most of my knowledge of Norwegian herring I owe to a most interesting report by Sven Runnström (6). It covers the herring fishery (of 1937 chiefly) from three angles; the location of the fish by echo, the estimation of the quantities of herring spawning from samples of spawn grabbed from the bottom, and the movement of cold-water fronts across the fishing grounds. These converging approaches show clearly the different phenomena occurring in what is probably the world's greatest herring fishery. The main features regarding behaviour are as follows:—

1. The Norwegian investigators seem to attach very little importance to small shoals, which they mention as offshoots from the main herring masses.
2. Most of the herring located by echo were in large concentrations, miles in extent. Fairly normal dimensions were 10 miles square, and one shoal in the Norwegian Deep was 20 miles long, and 30 metres thick.
3. All these large masses were recorded in deep water, mostly of 100 fathoms or more.
4. *Herring were always found at a depth of 75 fathoms in the daytime.*
5. They could be seen to rise in the gloaming. One case is mentioned of herring rising 50 fathoms in one hour between 6 and 7 p.m. (February 1937).
6. In hundreds of bottom sampling operations, when the echo-sounder was always kept working, *herring were never registered on the banks in daytime.*

7. From comparison of the quantities of herring registered by echo with the quantities estimated from grab samples to be actually spawning, it was thought that only a small portion of the main masses reached the spawning banks in shallow water.

Having stated the facts briefly as they bear upon the present subject, I will now detail one small part of the report which is important to my case.

In a table in which the quantity of "small" herring estimated from echoes and spawn samples to be present in the district is shown with the output of the fishery for 1937, it can be seen that in the three districts with depths of 25 to 70 fathoms the values of the quantities were as follows:—

| | |
|---|---|
| Quantity estimated from echoes ..... | 14·2 Hl. |
| Quantity estimated from spawn samples ..... | 2·9 „ |
| Quantity caught by all methods ..... | 0·8 „ |

In the other three districts where the depths are less than 30 fathoms the values were:—

| | |
|---|---|
| Quantity estimated from echoes ..... | 0·0 Hl. |
| Quantity estimated from spawn samples ..... | 0·3 „ |
| Quantity caught by all methods ..... | 0·36 „ |

That is to say, no herring at all were echoed in the shallow water. In the deeper water areas herring masses 10 and 15 miles long were recorded (but only small streaks on the actual banks of less than 50 fathoms), while none was seen in the other areas where the catch was 180,000 crans (0·36 million hectolitres).

During a visit to Norway last year I was able to spend a week on board a modern purse seiner. In effect a fish freighter carrying a pair of ring-net boats, this type of ship shows how catching methods are evolved by local fishery conditions; it frequently catches in one haul as much as our average drifter catches in a year. But I saw nothing while there to suggest any difference in herring behaviour from that seen in our own waters. In fact one of the echographs I obtained was a perfect picture of the rising groups in the three-stage behaviour just described.

We made this record while cruising across the bay just north of the Stat peninsula. After fruitlessly searching along the shore among fearsome-looking whaleback rocks we steamed out through the drifter fleet and echoed 9 or 10 separate small shoals at about 20 fathoms as we crossed the ground in the fading light. After locating and surrounding a small shoal (300 crans), we returned to anchorage until next day, when we learned that many of the drifters had lost nets with heavy catches. A lone boat was still hauling when we went out again, but our search in the daylight yielded no herring traces on the echo-sounder. The bottom was very uneven, with the depth generally less than 100 fathoms. From this, and other blank searches in daylight, it seemed to me that Norwegian herring were just as difficult to locate as ours.

There are apparently two quite distinct behaviour patterns to be seen here; in the deep water there is common occurrence of extensive

fields of herring at 75 fathoms in daylight, which rise to the surface without breaking up; in the shallower waters the behaviour becomes more complicated, and, so far as I could tell, similar to that seen on our grounds.

The great herring masses in the Norwegian Deep can be repeatedly crossed and plotted in daylight; they can be left and returned to days later in the same large dimensions. Since such a thing is unknown on other grounds, even on the heavy shoals at East Anglia, the reason for it seems to be the greater depth of water.

My friend, Mr. George Leslie, is very successful at echo fishing in Shetland waters. He is quite confident when steaming off to shoot that the herring will show echoes wherever they are. But he likes the deeper water. "Whenever we drop into 80 fathoms," he says, "there are the herring echoes." Their extent is often quite considerable, too. He sometimes sees them for the length of a fleet of nets, sometimes at the bottom, sometimes just clear of it, or higher. But he also told me that he would shoot if he saw three or four of the small shoals as shown in Plate 1. I have never fished with an echo-sounder at Shetland, but it is certain that the herring there are more easily echoed than those further south. In so far as the average depth of the fishing grounds is greater this easier indication of Shetland herring shows no disagreement with my general theory. How this changing behaviour from north to south may be due to this depth-gradient in the herrings' environment we may now discuss.

## General Conclusions.

Accepting the possibility that minor variations of behaviour may occur in any region we can restate the main facts about the three depth-zones as follows:—

| | |
|---|---|
| Deep zone | Wide fields of herring occur.<br>Echoed at 75 fathoms in daytime.<br>Up-and-down diurnal movement. |
| Medium zone | Herring seldom echoed in daytime.<br>Compact groups rise at dusk.<br>Swim occurs during darkness.<br>No wide fields of herring. |
| Shallow zone | Herring seldom echoed, except during swim.<br>Intense action; frequent swim.<br>No wide fields of herring. |

From this we see that the up-and-down movement, with some variation in its manner and time, is common to all depths. We may take it that the surface swim, as the culmination of the rise, is also common to them all. The two most important differences are seen in the daytime behaviour. If we leave for the moment the shallow zone, with its tidal complications, we have:—

| | |
|---|---|
| Deep zone | Wide fields of herring.<br>Echoes at high day. |
| Medium zone | No wide fields of herring.<br>No echoes at high day. |

The extensive masses of herring occur only in the deep water; here they can be echoed in the daytime at 75 fathoms. In the medium zone where no echoes are seen at high day, there is no evidence of widespread shoals at any time. Here we have two apparently parallel effects of the same cause.

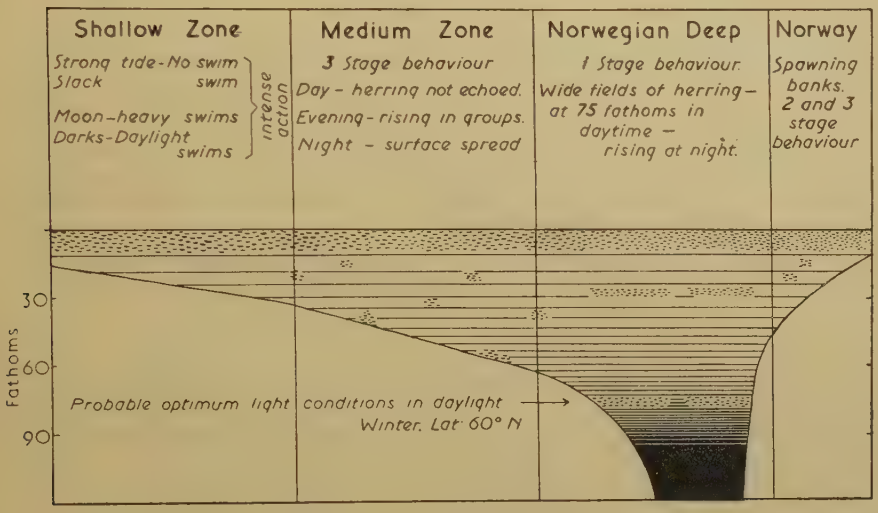



Figure 2. Diagram showing different patterns of herring behaviour in different depths of water.

Sven Runnström's lines of herring echoes totalled over 150 miles, and as he states simply that the herring were always found at 75 fathoms in the daytime it is reasonable to infer that at that depth, in Norwegian winter daylight, the light penetration is not strong enough to produce any further downward movement of the fish. If it is accepted that the herring need the optimum of twilight, or near-darkness as it may be, obtaining at that depth to be comfortable we have a working hypothesis for the more complicated behaviour of the shallower waters.

Runnström mentions the location, at the western side of the Norwegian Deep, of a spread of several miles of herring which ended near the slope of the North Sea plateau. The echoes undoubtedly ended at the slope, but did the herring? If we could see that echograph it would probably show at a glance the environmental intrusion which I am trying to emphasize:— the crossing of the herrings' natural daylight "floor" by the actual floor of the sea.

Whatever the amount of light penetration at 75 fathoms in winter may be, we may be sure that its equivalent in summer would only be found in a greater depth of water. From this it appears that the herring of most of our fisheries can seldom, if ever, find the comfort of what we will call their optimum darkness — except at night.

It is probable, however, that the herrings' need for this optimum is instinctive and due in some part to its survival value, so that their discomfort in the lesser depths would be alleviated by the protection of the sea bed beneath them. In the sense that no attack could come from below their proximity to the bottom would be like pressing the top of a thick shoal.

In all but the very deep zone, then, the herring are squeezed, in the daytime, between these two forces in their environment, the pressing action of light intensity, and the limiting action of the sea bed. The result seems to be the temporary abandonment of their natural shoaling formation.

There can be little doubt that the change from the shoal is to some kind of flat formation at the bottom; but we can say with certainty only that the change is from an echoable formation to one in which they are not echoable, and that the change is a direct consequence of the depth factor in the herrings' environment.

Can we go further and guess why the great masses of herring occur only in the very deep region? According to Runnström their average vertical thickness was 10 metres. What can we suppose would happen if in imagination we pressed the sea bottom upwards under a typical mass of herring some 10 miles square and 10 metres thick? If we assume that the fish are disposed in the proximity needed by their physical condition, the answer must depend very much on how dense this disposition is.

In medium zone three-stage behaviour I have assumed that the comfortable shoaling formation is accommodated during the daylight pressure by an outward spread into a two-dimensional form. But no spread is possible in the large masses, and the only possible result of our upward pressure must be an increase in the lateral congestion — if no rise of the upper layers of fish is permitted. Quite probably the density of large masses is much the same as that of the small rising groups in the medium zone. And if so, the occurrence of large masses in the medium zone might be prevented by the fact that their bottom congestion in daylight would be too great for comfort. Yet we have seen that great quantities of herring may occur at East Anglia without showing echoes, when if they were at the bottom their lateral congestion would be very great.

Another possible explanation is that once the herring have been pressed out of shoal formation the upward rise would be broken because of varying strength of photophobia in the different age-components of the herring community. The younger age-groups, being less sensitive to the light influence, would naturally be the first to rise, and the oldest age-groups last. This would account for the staggered

rise already noted in the medium-zone shoals, and in the same case we should expect the deep-water masses to be disposed with the youngest individuals at the top.

It would be unwise at present to do more than glance at this question because it is by no means proved that large fields of herring do not occur in the medium and shallow zones. Mr. G. W. Leslie has told me of shoals some miles wide spotted from the air on the Shetland grounds, and I can describe a single instance of seeing something fairly similar 50 miles E.S.E. of Peterhead. Over a 2-mile area I saw almost continuous echoes of herring at depths varying from surface to bottom. On a visual type of echometer the peaks were generally repeated from 5 to 15 times with short blank intervals, indicating a great many groups of varying sizes. This was at 6·0 p.m. (very dull and rainy) on 8. June 1937, on which day there was a new moon at 9·43 p.m. and a total eclipse of the sun. We shot there quite alone, and got 150 crans.

Apart from this one case I have never experienced widespread herring echoes, even on similar large catches. Because of this, and in the absence of any reports of large masses by the numerous Scottish drifters using echo-sounders, I have assumed these to be the exception in the medium and shallow depth-zones.

The Norwegian Deep shoals up on its western side to spawning grounds, i.e., the Viking, the Patches, the Reefs, etc. which are similar to those of Norway's fisheries. I remember fishing there on spawning herring, in 65 fathoms just west of the slope, in 1933 when we first had the echo-sounder. On Good Friday afternoon we steamed through an area that was obviously rich in herring; I have never seen "milkier" water, even at Smith's Knoll, and the gannets sat in scores, too full to fly though it was blowing hard. But no herring echoes could be seen.

The Marconi operator who sat watching the sounder just kept shaking his head in response to my frequent, somewhat impatient enquiries. The fact that 16 years ago my first experience of complicated medium-depth behaviour occurred only some twenty miles from the Deep where apparently mile-wide masses of herring might have been echoed in daylight shows how chancy the obtaining of fisheries evidence can be.

It can be safely said, I think, that the changes described here as one, two, and three-stage behaviour are due to changes in the environment. That they are caused by external, and not internal factors is shown clearly by the fact that the 24-hour three-stage rhythm can be seen in late summer in herring in the same pre-spawning state as those at East Anglia where the action is intense, and the swim more frequent.

We can see that the changes may not be ascribed as all due to the depth gradient alone. In the shallow zone the influences of tidal streams, probably producing the frequent swims, and of the moon, probably causing the daylight swims, are conflicting, and difficult to separate from the influence of the lessening depth with its corresponding increase of light penetration. Nevertheless I think it quite probable that the actual modes of behaviour, i.e., one stage in the deep zone, three stage in the medium, with the compact rising groups an essential

feature, and two stage in the shallow, being simply swim and non-swim periods without the shoaling stage between, will eventually be found to be dependent upon the depth of water.

The acceptance of the foregoing conclusions on herring behaviour may shed some light upon the subject of migration. The great movements upon which our herring fisheries depend occur seasonally with remarkable regularity. The fact that the fish spend most of their time at the bottom shows that their journeys are made in relation to the sea-bed geography; the many currents or streams, and the different conditions of salinity, temperature, and plankton content in the water appear as only secondary factors.

The adult herrings' orientation to the bottom will also probably explain the holding effect of rising grounds where the best fishings generally occur. We can understand that herring migrating over the ground would tend to concentrate on the hills. Any slowing up of the leaders would cause this. But the holding effect is also noticeable on both sides of banks, or tongues of ground. The fish seem reluctant to move either uphill or down, and the result is a denser concentration on any appreciable slope, which will persist until the migratory impulse is restored — usually by a favourable wind.

My experience suggests that except when actually spawning the herring are always moving, and that their movement is speeded up or retarded considerably by wind effect — which may, however, be indirect — and is guided very much by the bottom contours and to a lesser degree by water conditions. I believe that the direction of swim shows the direction of migration, and suggest this as a useful line for future investigation.

H a r d y and S a v a g e (9) have inferred that areas of dense phytoplankton will sometimes divert the normal migrations of herring. Beyond the notable case of the 1933 autumn fishing I have no experience to support this, but I must agree almost entirely with the theory of poor catches in these areas. The working of this rule is complicated by the weather, and perhaps the tidal factor. It may be stated in this way:— heavy phytoplankton plus calm weather invariably means a poor catch; but in breezy weather heavy phytoplankton does not preclude a good catch. The explanation is that the herring may be below the greatest density of the plants, and do not rise through them unless stimulated in some way.

On young feeding herring the plankton indicator is a definite help to fishing. In scarcer plankton times, if the nets can be shot in an oasis of feed, a superior catch is certain. But while it is reasonable to assume that hungry herring would tend to linger in water with a high *Calanus* content, I feel doubtful whether concentrations of food organisms have much influence on the migrations of any but the youngest age-groups.

The important plankton work being done must strengthen our grasp on this aspect of the fisheries. In the meantime I suggest as a fisherman that the Indicator could be better used in a slightly different

way, that is, by taking only clean or "dirty" disks as the criteria of higher or lower catches.

Green or brown disks are comparatively rare, except in September, but they are frequently found clogged with a colourless matter (a form of the colonial flagellate *Phaeocystis,* I am told), almost like white of egg, which makes any animals on the disks appear quite lifeless. I have no doubt that many light fishing periods in calm weather are due to the prevalence of this organism. If skippers could be taught to recognize and avoid this (as well as brown and green hauls, of course), attending not to the amount of feed, but only to its liveliness on the gauze, which is an infallible sign of a clean disk, then I believe that the rule, *clean disk means higher catch; dirty disk plus calm weather means lower catch,* would yield consistently better results, not only during the early feeding months, but throughout the summer.

Here we should take note of certain changes in behaviour which are not due to environmental influences. We have seen that the very young herring in the whitebait stage frequent the surface waters during daylight. They can be watched in many waters around our coasts in summer, and it is doubtful if at this age they go to the bottom at all. To go a step further, herring of one and two years old are too small to be seen in commercial drift-net catches, but H e n r y W o o d (7) has shown that these herring do not occur in very deep water, that they are seldom found in the stomachs of the deep-water fishes, and that only on reaching maturity in their third or fourth year do they move into deeper water to join the adult shoals.

My own experience of young feeding shoals off Shields in pre-war days indicated an action somewhat looser than three-stage behaviour. We had many cases of seeing frequent small echoes before shooting where our better average catches were taken. Very small peaks kept showing intermittently at mid-depth, suggesting that comparatively sparse shoals of these small fish were well off the bottom in the early evening, perhaps feeding among the copepods which were usually present. There was no evidence of the compact group stage at all. Since using the recording type of sounder the nearest thing I have seen to this was on a concentration of herring in September 1948 which could be easily echoed in fairly extensive shoals. These were very small fish, and accurate fishing by echo-location was notably simple after the scarcity of echoes on large herring throughout the summer.

It is fairly evident that a progressive change in behaviour can be correlated with age. The herring apparently do not shun the light during their first year or two; the fact that photophobic action develops as the fish approach maturity, whether it is deferred instinct or the need for orientation to the bottom as a pre-requisite to spawning, shows a change that is due to internal rather than external conditions.

How far this trend continues it is difficult to say. We do know that the older herring are usually predominant in the Fladen Ground trawl catches. C. E. L u c a s (8) shows that while the small herring leave the bottom at night the larger ones tend to stay there, which

suggests that the oldest fish may possibly reach an armchair stage in which they hardly rise from the sea bed at all.

There are other behaviour variations of internal origin, due to the changing physical condition of the fish, but little evidence supporting my experience is available yet. The herrings' annual cycle goes from the spent stage through a period of intensive feeding to the pre-spawning pause, when they are neither feeding nor spawning, and thence to the actual spawning. Some alteration in action would seem to be a natural outcome of these physiological changes.

The close formation of the midwater groups would not be conducive to easy feeding, and this three-stage behaviour occurring in hungry herring would mean that general feeding could only take place during the surface spread at night. Herring being fed in an aquarium (on chopped mussel) take the food by positive selection from some distance, and in natural conditions their feeding may be a combination of this and the automatic action of mouth and gillrakers as a plankton sieve.

I have definite experience that the swim in younger feeding herring is protracted. Surface echoes can be watched for hours during the night in early summer. The absence of these echoes with good catches from July onwards seems to indicate that the swim then is of much shorter duration. The swim in spawners is very dense and local. The limiting of the surface spread is shown by the finding of blank nets on both sides of a heavy catch, and of herring coming thick in a few nets of the fleet.

So far as I know there is no evidence to support the opinion that the herring disperse after spawning. Spents are taken in large shots by drifters, and in trawling. Fishermen say that spents "swim very sharp" because they are hard to shake out of the nets, but this is probably caused by the leanness of the fish allowing them to get more deeply meshed.

At present we can only note these possible behaviour variations as being connected with the different conditions of development in the fish; it is possible that future investigations will enable them to be classified more definitely.

The recognition of different behaviour patterns in different depths of water will explain to some extent why we are behind some fishing countries in the development of the echo-sounder as a fish finder. In Norway's favourable conditions with widespread masses of herring, and also cod, the official echo-location of shoals for the benefit of the fishermen is well established. In our own waters such scientific help has not yet been possible; although many drifters are now fitted with echo-sounders their use in the location of herring is by no means general, or of unqualified benefit to fishing results.

The facts that good catches will occur where no herring have been echoed, and that the evening rising groups are comparatively small — often so small as to seem not worth shooting on — will show that summer echo-fishing is not easy. With the intense action at East Anglia the difficulties of echo-location are even greater. But even so, some official attempt to exploit this marine "eye" is necessary for the efficient

development of our fisheries. When the possible variations of behaviour are realized, I believe that the operation, by the Ministry of Fisheries or the Herring Industry Board, of scouting ships equipped with echo-sounder and radio will improve landings in summer, and perhaps to a lesser extent in autumn.

The usual procedure of drifter skippers is to return to the ground of the day's best catches. It is sometimes possible to maintain contact with a moving body of herring by reason of the number of boats working; that is to say, even though the herring have moved some miles the spread of boats will ensure that some nets are into the fish. Then the course and distance is altered accordingly for the next night, and so on. But the contact is nearly always lost when fishing stops at the weekend, and sometimes two or three nights are wasted before it is regained, or another concentration found. My experience suggests that herring are echoed more easily when migrating strongly. But whether this is the case or not, it is quite probable that echo-searching boats would be of great value in keeping the fleet in touch with moving herring in summer, as well as in exploring the unfished grounds.

Another fact emerging from echo evidence is that the swim may not be such a mystery after all. It would seem that the catching of herring in drift-nets depends simply on the fish being where the nets are. There is no visible reason why herring should not be caught at the bottom in daylight as well as at the surface at night providing a suitable catching engine could be placed among them. We already have this in the trawl, which is an active method of capture compared with the passive drift-net. In Norway great quantities of herring are caught by means of bottom nets, which I presume are anchored like those in some of our Scottish fisheries, but whether they fish in daylight I cannot say. If the herring at East Anglia, when not taking the net, are stemming the tide in close formation at the sea bed, an efficient trap like the trawl or seine-net moving even slowly before the tidal stream might be effective in catching them.

The long drift fleets, so efficient during the swim, or surface spread, are of little use with the compact groups echoed in three-stage behaviour. But here the enveloping ring-net is most deadly. On such midwater shoals the Norwegian purse seine, a similar but larger instrument, would be equally effective in fine weather on grounds outside the ring-netters range, though some improvement in handling their bulky catches would be necessary for herring not to be used for oil and meal.

In spite of much useful research there is a great deal that we do not know about the herring and the factors affecting its behaviour. Why are some nights bad for fishing and others good? A shift of wind or a sudden calm will often cause light landings, and upset the calculations of those who control the fishing. Why are some catches, especially in ring-nets, preponderantly male fish and other catches mostly females? Fishermen have good ideas about these and many other vagaries of the "little people", but they cannot explain them. Catches in any given

conditions are still far from predictable, and evidence on behaviour must eventually be a help towards efficiency in this direction.

Why is it, I asked in beginning, that the herring can be found by echo at some time and not at others? I believe that the answer to this question lies in the two and three-stage patterns of behaviour I have described. Though it may take some years to prove or disprove, this theory of light avoidance in herring is offered as a small contribution to our knowledge of the way of life in the sea, and in the hope that it may be of some help in future herring investigation.

## Summary.

Changes in herring behaviour can be of two kinds; those due to internal conditions of the fish, and those caused by external factors, or environment.

Of the former an important one is the progression from an entirely surface life in the young to a partly, and perhaps preponderantly demersal life as the herring grow older. Another suggested is the change in the duration of swim, protracted in feeding shoals, and more intense in non-feeders and spawners.

Externally caused changes are described as due to the conflicting influences of light intensity and depth of water, and in the shallow zone to the influence of the moon and tides.

The argument is based on the author's fishing experience with echo-sounders, supplemented by Norwegian and other evidence on herring behaviour, for which grateful acknowledgment is made.

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# Factors Influencing the Runs of Elvers in the River Bann, Northern Ireland.

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## I. Introduction.

### a) Sources of Biological and Meteorological Data.

The River Bann in Northern Ireland supports one of the largest fisheries for silver eels (*Anguilla anguilla* L.) in western Europe. The Bann flows from Lough Neagh to the sea and this lough, which covers 153 square miles, is the largest lake and most important eel producing area in the British Isles (See Figure 1). Associated with this eel fishery is a "fishery" for elvers which has been described by Menzies (1936) and Frost (1950). This fishery was started in 1932 by the Government of Northern Ireland as it was felt that obstacles built in connexion with River Bann drainage operations might interfere with the natural run of elvers up the river. The elvers are therefore trapped at the top of the tideway, at Cutts weir, 6 miles inland from the sea, and transported up the river by lorry. Trapping experiments were carried out in the years 1932—1935, and from 1936 onwards trapping conditions have been stable and it is maintained that almost all the elvers are trapped at this weir. The elvers are removed daily from the traps, boxed, taken up river by lorry, and replaced in the Bann river system at four points. These places, Hutchinson Quay, Portglenone, and New Ferry on the river, and Toome on Lough Neagh are approximately 18 to 36 miles above the traps, i.e., 2 to $3^1/_2$ hours by motor transport. Between 1915 and 1935 the elver population was also increased by importing elvers from the River Lagan in Northern Ireland and River

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Severn in England. The numbers imported ranged from 187,000 to 3,000,000 a year, small quantities in comparison with the 15 to 30 million which enter the River Bann naturally each year.

The capture of all, or nearly all, the elvers migrating up a large river presented a unique opportunity to investigate the factors controlling elver "runs". Through the kindness of Mr. W. J. M. Menzies,

Figure 1. River Bann showing places mentioned in the text; inset map of Ireland to show location of River Bann and Lough Neagh, and the towns Armagh and Londonderry.

Freshwater Fisheries Advisor to the Ministry of Finance, Northern Ireland, and the late Major P. E. Shepherd, Director of Works for the Northern Ireland Government, records of these catches were put at the disposal of the Freshwater Biological Association. This paper presents an analysis of these records in relation to the prevailing water and weather conditions.

Records of distinct elver "runs" have been kept from 1933, and records of daily catches from 1938 onwards. This paper deals with an examination of the catches from 1936, when trapping conditions were stabilized, to 1943. The results are related to other work on elvers, Menzies (1936), Heldt and Heldt (1929), Wimpenny

(1929), and to personal observations (unpublished) on elver runs on the Rivers Severn, Leven, and Wyre in England. Elver "runs" have been correlated with tidal data, and with water discharge measured in cubic feet per minute over Movanagher weir which is 11 miles upstream of the Cutts traps. Daily maximum and minimum air temperatures, rainfall, wind, and hours of sunshine records were kindly supplied by the Air Ministry from the nearest meteorological station to the mouth of the river, the University Station of the Meteorological Office at Armagh.

**b) Trapping Methods.**

The two large concrete traps, each with a straw-lined slipway have been described in detail by Menzies (1936). They lie at each end of the Cutts weir at the head of the tideway. During the season these traps fish continuously, and are, as far as possible, emptied once, twice, or three times a day according to the number of elvers running. Wire netting is fixed over the slipway to prevent gulls, rats, and other predators taking toll of the mounting elvers.

**c) General Characteristics of the Elver Migration.**

The elvers are caught between March and late June. The starting date of the migration for the years considered here varied from 6. March (in 1943) to 15. April (in 1940 and 1941); the latest elvers were trapped on dates between 13. June (in 1942) and 7. July (in 1943). Between the starting and finishing dates of the season the numbers rise slowly to a maximum about halfway through the season then gradually decrease. The migration may be continuous, as in 1940, or divided into a number of "runs" varying in number from two, as in 1941, to seven, as in 1943. A "run" is here defined as the number of elvers migrating in a continuous stream naturally distinct from preceding and succeeding streams. Runs, during the years considered, lasted for any number of days from two to sixty. The total weight and number of elvers (weighed in pounds) caught per season may also vary considerably, for example, from 20,606 pounds (9340 Kg.) about 20,000,000 elvers in 1943 to 33,645 pounds (15,000 Kg.) about 30,000,000 elvers in 1941.

In this paper the following points are discussed for the years 1936 to 1943:—

1. The variation in numbers of elvers from year to year and the factors likely to influence this variation.
2. The separate factors likely to influence the elver migration and divide it into distinct runs. Tide, flood, temperature, and wind, and the interaction of these various factors are considered.

**d) Sources of Inaccuracy in the Correlations.**

1. The records available give the number of elvers transported and set free up the River Bann rather than the number taken in the Cutts traps each day. This is evident from the regularity with which box groupings, e.g., "four boxes" were removed from the traps, though it

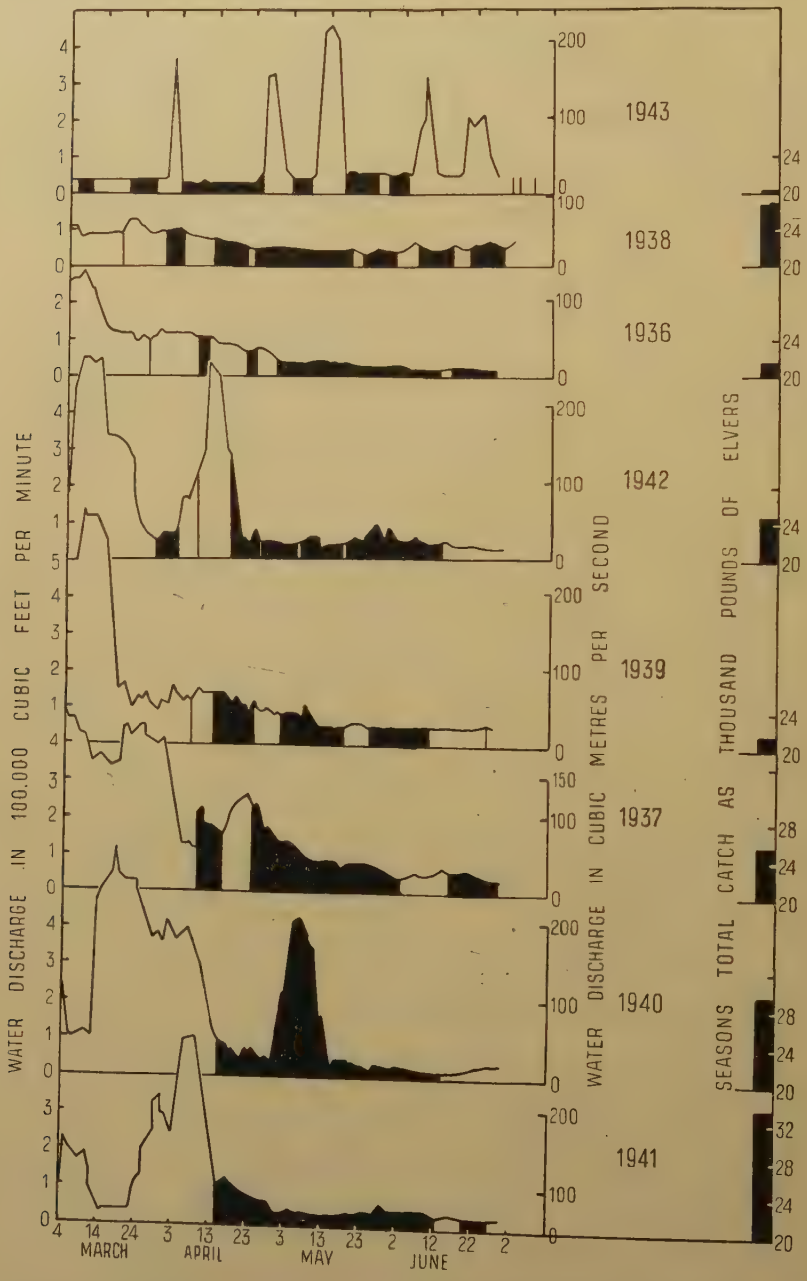


Figure 2. Elver runs in relation to river discharge.
Seasons are arranged in order of the date on which migration into fresh water started. Solid shading denotes days on which any elvers were trapped. The season's total catch, expressed as thousand pounds of elvers, is given at the right of the graph.

was stated that the traps were emptied as nearly as possible each day. It was felt that this error was too large to allow day-to-day correlations to be of value, but seasonal, monthly, and weekly totals, and totals for runs have been used, as the error due to a few elvers remaining in the traps until the next day is reduced when large numbers are considered.

2. A proportion of the elvers crawl up the vertical face of the Cutts weir and so escape upstream, and elver runs are reported above the Cutts weir at Carnroe and Portna weirs. The proportion escaping is reported to be small, but will not be constant as it will depend on the amount of water flowing over the weirs and possibly other factors. A heavy flow or very dry weather probably prevents the elvers climbing the weir face.

3. The only temperature records available are air temperatures, and it is water temperatures which will affect the elvers. As a general rule there is a time lag between air and water temperatures and this lag, as it depends upon other weather conditions, will not be constant. Thus it is not known just when a fall in water temperature will follow a drop in air temperature and affect the fish. On the other hand water temperatures are affected far more by other factors, such as floods, which are themselves likely to affect the elver runs, e.g., *via* water pressure, so that air temperatures may give a truer picture of the effect of temperature itself on the elver runs.

These air temperatures are from Armagh, 20 miles from Cutts weir so they will differ slightly from the temperatures where the elvers are trapped. The river flow and air-water temperature lag may, however, help to lessen this source of error. There will also be some differences in wind direction and rainfall between Armagh and Cutts weirs.

4. The effect of floods, measured as water discharge over Movanagher weir about 12 miles upstream of the traps (Fig. 1), may be influenced by the operation of sluices at Cutts weir.

5. A further point to be considered is that wherever possible weights (pounds) of elvers trapped are used as the elvers are weighed and the weights are more accurate than the calculated numbers. Work on elvers in other rivers has shown that the elvers lose weight as well as length until the metamorphosis is complete and they are fully pigmented (Strubberg 1913). Thus there will be more elvers to the pound as the season advances. There may also be a variation in numbers to the pound from year to year.

Despite these sources of inaccuracy the records of capture of almost all the elvers in one river over a large number of years provide a unique opportunity of observing the factors which influence the elver runs.

## II. The Total Numbers of Elvers Trapped each Year.

It is not known whether all the elvers which enter the estuary each year go upstream, but that they all do so seems unlikely as many small eels appear to live in the estuaries of most rivers. If only a proportion continues upstream, then the number so doing is likely to be influenced mainly by conditions suitable for upstream migration; but if all or

nearly all elvers go up, the number migrating will reflect the number of elvers in from the sea. The evidence is at present in favour of a very high proportion moving upstream every year, which means that numbers in from the sea, rather than suitable "running" conditions, will affect the total numbers trapped. The numbers in from the sea will in turn be influenced by the numbers of spawning silver eels, the amount of spawn, and probably even more by sea and weather conditions and number of predators in the Atlantic, and the attraction into this particular river.

Table 1 and Figure 2 show the relation between the length of season, number of «running" days, i.e., days during the season on which any elvers ran, total catch per running day, and number of distinct runs during the years 1936—1943, years when trapping conditions were constant.

**Table 1. The Number of "running" Days, total Catch, Catch per "running" Day and Number of distinct "runs" in long and short Seasons.**

| Season | 1943 | 1938 | 1939 | 1942 | 1941 | 1940 |
|---|---|---|---|---|---|---|
| Duration of season (days) | 123 | 102 | 80 | 77 | 73 | 60 |
| Number of "running" days | 53 | 60 | 46 | 53 | 57 | 50 |
| Total catch for season (pounds) | 20,606 | 27,072 | 21,498 | 24,462 | 31,790 | 29,564 |
| Catch per "running" day (pounds) | 396 | 451 | 467 | 456 | 590 | 591 |
| Number of distinct "runs" | 7 | 7 | 5 | 5 | 2 | 1 |

In the short seasons the shortness is due mainly to a late start (see Figure 2) and the number of running days is independent of the length (duration) of the season and is remarkable constant from year to year (Table 1). The average catch per running day is therefore higher in seasons with a high total catch. Short seasons, e.g., 1941, also tend to be seasons with a high total catch of elvers (possibly for reasons considered below). The late starting seasons are not extended to compensate for the late start. Since it is unlikely that the elvers in late starting years can know that the season will be a short one this constancy in number of running days, in years of very different temperature and water conditions, suggests that it is the number of elvers present in the estuary (indicated by the season's total catch) which controls the number of elvers running per day, rather than the number of elvers running per day determining the season's total catch. It seems that the "pressure" of elvers in the estuary may be an important factor controlling the runs. This idea is supported by the observations that factors such as flood, tide, etc., which affect the runs, have relatively less effect the greater the seasonal total of elvers (see below).

Apart from the uniformity from year to year in the number of running days, there is a tendency for a greater seasonal total of elvers to be taken in short seasons, after a late start, and *vice versa* (Table 1). The number of distinct runs is also inversely proportional to the duration of the season (as can be seen from Figure 2) and the total catch. Thus there are two extreme types of season connected by intermediate types:—

1. Seasons in which an early starting date is correlated with a long season divided into distinct runs by floods etc.; such seasons are associated with a low total number of elvers.

2. Seasons in which a late starting date is correlated with a short season of one continuous run independent of floods, tide, and weather conditions; such seasons are associated with a high total number of elvers.

Type 1 with an early starting date, as will be shown later and as is clear from Figure 2, follows a mild winter and absence of floods in March. Type 2 follows a hard winter with heavy floods in March which delay the starting date.

At Commacchio the Italian eel fishers open the river sluices in the early elver season to allow more fresh water out to sea (Henking *et al.* 1908). This is believed to attract elvers into the lagoons from the sea, and it seems that the late March and early April floods have the same effect on the River Bann, that is, they attract large numbers of elvers in from the sea. The effect will depend on the flood coinciding with the passage of elvers in the sea past the estuary mouth.

The coincidence of a high total number of elvers and sustained March and April floods cannot be proved statistically on the data at present available, and exceptions to the sequence are found in 1938 and 1939, but the figures are strongly suggestive of a correlation. Figure 2 gives the seasons in order of the starting date of the migration but it can be seen from this graph that if the seasons were arranged according to the date of the premigration floods, irrespective of the size of the floods, they would fall into the following order:—

| Years in order of date of premigration flood | 1943 | 1936 | 1942* | 1939 | 1938 | 1937 | 1940 | 1941 |
|---|---|---|---|---|---|---|---|---|
| Seasons total in order of magnitude | 8 | 7 | 5 | 6 | 4 | 3 | 2 | 1 |

(* also early April floods)

This suggests that the date of flood (or rise in level; this was very slight in 1938) rather than its magnitude may be important. The later the premigration flood the larger the catch. There are also probably fluctuations in the numbers of elvers in the sea off the estuary mouth.

This combination of a high total of elvers in the estuary, almost all of which eventually run up into fresh water, together with the short season, leads the elvers to run continuously despite other factors such as

floods, tides, and weather conditions, which in the long seasons appear to check the migration and divide it into distinct runs. Thus it seems that the numbers of elvers available will affect the migration more than meteorological conditions, and determine the number of distinct runs that there are in each season. Overcrowding in the estuary is likely to lead to continuous runs, and may act as a trigger initiating a run. The absence or rarity of stragglers on the Bann or other rivers, such as the River Severn and River Leven in England (personal observation), supports this view, and indicates that runs only occur when a certain threshold number of elvers are ready to migrate.

To sum up, in years with heavy floods in March and early April the starting date of the elver migration into fresh water will be delayed. It is probable that when the migration starts late it will be continuous despite later floods, tidal and weather conditions, and that the short season will yield a high total of elvers, probably owing to the fresh flood water attracting large numbers of elvers in from the sea. The "pressure" of elvers in the estuary may be an important factor in controlling runs.

## III. Factors Influencing the Elver Migrations.

It has for years been recognized that many environmental factors, in extremely complicated interaction, affect the runs of elvers into fresh water. Much field observation and careful experimental work will be necessary before the factors initiating the migration and supplying the directional force guiding the elvers to the new environment are quite clear. Investigation of the different environmental factors causing or allowing the elver runs to start and stop provides one of the best ways of attacking the problem. Observations already made suggested that the following factors might be concerned:—

1. **Tide.** Spring or neap tides, flood or ebb, may all have different effects on the run.
2. **Floods.** Both the physical force of the water and coincident temperature changes are likely to affect the runs. Rainfall itself might also affect the runs, in addition to causing floods, and might have a temperature effect.
3. **Temperature.**
4. **Wind.**
5. **Light.** Unfortunately from the data available it was not possible to separate day and night catches. The light factor is therefore ignored in this paper. On other rivers, e.g., the Severn and Leven, light does not appear to affect the runs, for the elvers run equally well by day as by night (personal observation). On the River Severn elvers are fished for at night because the fisherfolk are at other work all day, hence the erroneous idea has arisen that the elvers move up only by night.

Any of these factors, singly or in combination, might be responsible for starting the migrations and directing the elvers, as well as allowing the elvers to run only under certain conditions.

**1. Tide.**

In three years of observation on the River Bann, 1933—1936, Menzies (1936) found that each run of elvers coincided with a spring-tide period and that a real run occurred only twice during the neap tides. Mr. Menzies concluded that during neap tides no elvers normally arrive in the river, but further data from the River Bann have since modified this conclusion.

An analysis is here made of elver runs in relation to tidal height during the six years 1938—1943 (Table 2). The mean daily maximum tidal height for days throughout the elver season of these years was found to be +7·25 feet (Londonderry data), and for this analysis days on which the tide rose over 7·5 feet were considered to be days of "high" (spring) tide, and below this days of "low" (neap) tide.

**Table 2. The Effect of Tides on Elver Runs.**

| | Tides | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | Total |
|---|---|---|---|---|---|---|---|---|
| Number of days elvers ran | Spring | 34 | 27 | 26 | 29 | 32 | 36 | 184 |
| | Neap | 26 | 19 | 24 | 28 | 22 | 16 | 135 |
| Total weight of elvers caught per season (pounds) | Spring | 17,609 | 11,109 | 14,072 | 15,667 | 13,691 | 14,620 | 86,768 |
| | Neap | 9,463 | 10,389 | 15,492 | 17,978 | 10,952 | 5,986 | 70,260 |
| Weight of elvers caught per running day (pounds) | Spring | 518 | 411 | 541 | 540 | 428 | 406 | |
| | Neap | 364 | 541 | 645 | 642 | 498 | 374 | |

| | | Number of Days | Total Weight | Weight per running day |
|---|---|---|---|---|
| Average | Spring tides | 30·6 | 14,461 | 470 |
| | Neap tides | 22·5 | 11,710 | 510 |

Table 2 shows that:—

a) During the 6 years elvers ran on an average of 30·6 days of spring tides per season, and 22·5 days of neap tides. In all 6 years the elvers ran more often on days of spring tides.

b) In 4 of the 6 years a higher seasonal total of elvers was taken from springs than from neaps. The total weight per year averaged 14,461 pounds from spring tides, and 11,710 pounds from neap tides. This result is partly explained as the elvers ran more often on days of spring tides.

c) The weight of elvers trapped per running day averaged 470 pounds per day from spring tides and 510 pounds per day from neaps, showing that slightly more elvers ran on the relatively fewer days of neap tides. This result is, however, weighted as elvers ran on neap tides more often in high total years.

In Figure 3 the difference in number of running days from spring and neap tides is plotted against the season's total catch. This graph shows clearly that when the season's total is low the elvers tend to run

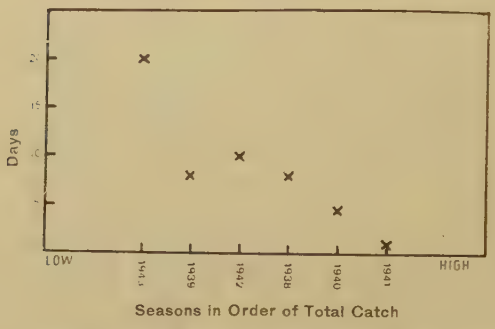


Figure 3. Effect of tide on elver runs. The number of days of spring tide on which any elvers ran minus the number of days of neap tides on which they ran, plotted against the seasons arranged in order of total catch.

more often from spring tides, but when the total is high the tide has relatively little effect. The effect of tide on the numbers running per day is over-ruled by some other factors, probably the number of elvers in the estuary and also floods. When floods have a great effect on the run, e.g., as in 1943, tides have relatively little effect in stopping the migration.

The Bann figures give no data on whether the elvers run mainly on the flood or ebb tide. On the River Severn elvers swim upstream near the bank on the ebb tide only; whether they ride up on the flood as well, or proceed only by active swimming on the ebb, is not yet known.

**2. Water Discharge and Rainfall.**

It has already been mentioned that a sustained high discharge of water in March and early April tends to be associated with a high seasonal total of elvers, and it is suggested that this is due to the attraction of elvers into the estuary by the fresh water pouring into the sea. It has also been mentioned that floods delay the starting date of the migration into fresh water. Figure 2 in which the years are arranged in order of the starting date shows this clearly, and in Figure 4 in which the starting date is plotted against the total discharge for March the connexion between these two is established, as a regression is found to be statistically significant. Whether this delay is due to the physical force of the water, or lowering of the temperature, or both, is not yet clear.

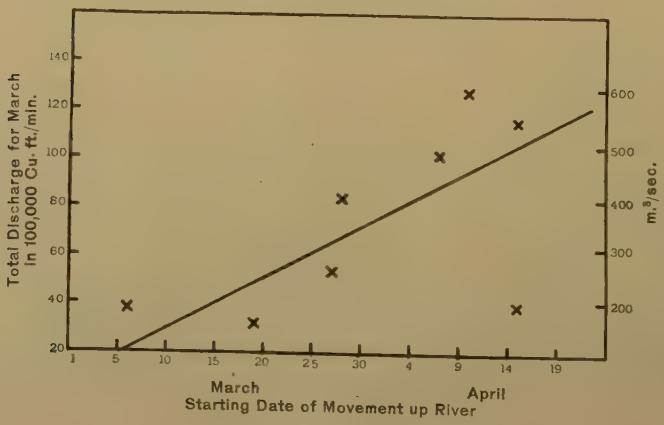


Figure 4. The starting date of the movement of elvers up the River Bann plotted against the total water discharge for March for the years 1936 to 1943.

Floods also appear to be effective in stopping runs, particularly early in the season and in seasons with a low total of elvers, e.g., 1943. The threshold discharge which will stop a run is influenced by other factors, probably the number of elvers present in the estuary and perhaps the temperature, and is not constant from season to season.

**Table 3. Water Discharges at which Elvers ceased to run in different Seasons.**

| Year | Total catch of elvers (pounds) | Approximate threshold discharge cubic feet per minute |
|---|---|---|
| 1943 Long season: low total catch | 20,606 | 90,000 cu.ft./min. (41 $m.^3$/sek.). |
| 1942 Intermediate | 24,643 | 120,000 cu.ft./min. (54·5 $m.^3$/sec.) except for 250 pounds in 5 days with discharges up to 280,000 cu.ft./min. (127 $m.^3$/sec.). |
| 1940 Short season: high total catch | 29,564 | Elvers ran continuously despite discharges up to 430,000 cu.ft./min. (195 $m.^3$/sec.) though the quantity of elvers trapped per day was slightly less with high discharges, e.g., av. 575 pounds per day for 13 days with discharge over 100,000 cu.ft./min. (45·5 $m.^3$/sec.). av. 656 pounds per day for 14 days with discharge under 100,000 cu.ft./min. (45·5 $m.^3$/sec.). |

Below the threshold of the season the number of elvers trapped was independent of the water discharge. Owing to the rarity of big floods late in the season reliable statistical tests could not be applied to the data available.

To sum up, high discharges, by taking freshwater well out to sea, probably attract elvers into the estuary. There is a statistically significant correlation between floods and the date of the start of migration. Besides delaying the starting date floods may also check the migration, particularly if the season's total of elvers is low and the starting date early.

In addition to the influence the rainfall has on the elver runs as water discharge, heavy rain may itself check a run temporarily; the check in the run on 17.—18. May 1942 appears to have been due to this factor. This may be a temperature effect, the coldness of the rainwater stopping the run. Wind direction and force and air temperatures will influence the temperature of the rainwater.

**3. Temperature.**

Air temperatures taken at Armagh, 20 miles from the traps, are the only temperature data available. The disadvantages of using these air temperatures have already been mentioned. Flood is one of the main factors influencing water temperature and flood itself has been shown to affect the elver runs.

Concerning air temperatures, attempts have been made to see whether:—

a) the starting date is related to the temperature advance of the season and/or is dependent on a minimum threshold temperature below which elvers will not run,

b) the occurrence of runs is limited by temperature,

c) the numbers of elvers running is influenced by the temperature either during the season or before the start of migration.

Weekly average temperatures (mean of daily maximum and minimum air temperatures) have been used. The steady increase and decrease, as the season advances, in the number of elvers migrating, makes statistical tests unreliable.

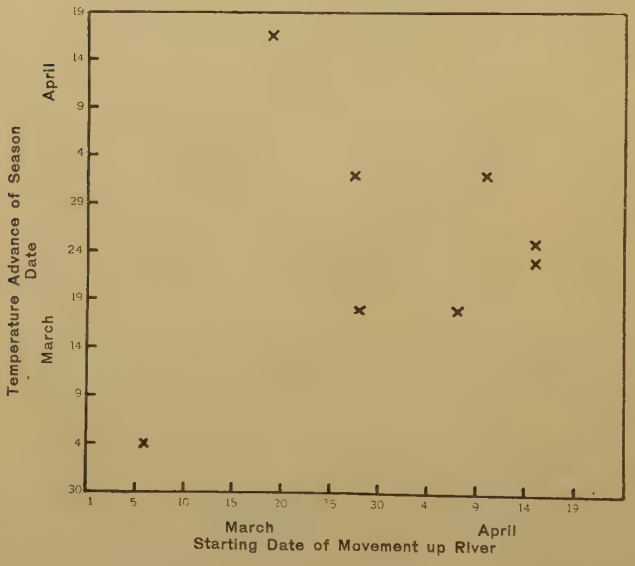


Figure 5. The starting date of the movements of elvers up the River Bann plotted against the "temperature advance" of the season indicated by the date of the end of the week in which the average mean weekly air temperature was first over 50°F. (10°C.).

a) Temperature and Starting Date.

The date at which the mean weekly air temperature was first over 50°F. (10°C.) has been taken as an index to the advance of the season. Figure 5 shows this date plotted against the date of the first run, and it is obvious that there is no correlation between the temperature date and the starting date.

The mean weekly air temperatures around the starting date ranged from 43·7°F. (6·5°C.) in 1943 to 48·4°F. (9·1°C.) in 1936. There was no threshold temperature for the start of the migration in spite of the fact that the expected trend for temperature to increase with the advancing season was not shown to any marked degree.

Thus from these data it appears that temperature does not play as large a part in determining the start of the migration as was believed from observations based on water temperatures from other rivers.

b) The Limitation of Runs by Temperature.

Menzies (1936) states a frosty night to be a definite deterrent to the run. During the years 1938—1943 the minimum air temperature was never below 32°F. (0°C.) for more than three days at a time, and the records provide no evidence that the low temperature affected the run. It is possible that the run may be checked over night if frost occurs, but that those elvers temporarily held back might run as soon as the temperature rises, i.e., within a matter of hours. One year, 1940, was studied in more detail, correlations of the mean and minimum weekly air temperatures and daily temperatures (allowing various time lags) being made with the catches. These tests indicated that the migration is on the whole independent of temperature.

c) The Influence of Temperature on the Number of Elvers Running.

There is no evidence that fewer elvers run at lower temperatures. The average temperature for the four months March, April, May, and June is remarkably constant (Table 4) and the figures show that the total yield of elvers is not influenced by temperature during the elver season.

**Table 4. Annual Total Catch compared with Mean Air Temperatures for March—June.**

| Year | Average air temperature March—June | Seasonal total of elvers (pounds) |
|---|---|---|
| 1941 | 48·4°F. (9·1°C.) | 33,645½ |
| 1942 | 50·3°F. (10·2°C.) | 24,606½ |
| 1943 | 48·3°F. (9·0°C.) | 20,606¼ |

The data available suggest that temperature is not the main factor influencing elver runs, although the run may sometimes be checked by frost, north wind, and heavy rain, all of which might act through a fall in water temperature. Whether floods influence the elvers through an accompanying fall in water temperature, or whether a fall in water temperature appears to affect the elvers only as it represents an index of flood (which may influence the elvers in some other way such as through the physical force of the water), has yet to be discovered.

**4. Wind.**

Menzies (1936) notes a cold northerly wind to be a definite deterrent to a run and states that the largest runs occur with south, south-west and west winds, warm showers and moist weather. Wind records from Armagh taken at 0900 hours every day have been correlated with the number of elvers trapped. As the wind often blows from a different direction on consecutive days the results are entirely dependent on the thoroughness with which the trap is emptied each day.

Polar dot diagrams were, however, made for the years 1938 and 1939. These showed that (a) elvers might run when the wind was in any direction, (b) there was no quantitative difference in number of

elvers caught with different winds. The numbers of elvers taken with different wind directions were also compared for 1940, a continuous run year, and 1943, a year with many runs. As the wind blew mostly from one or two quarters of the compass only throughout these seasons, statistical tests could not be applied.

From the data available it appears that a north wind does not always stop a run, though like frost it might do for a short period of hours or a day or so, as on 22. April 1938. Strong winds from other quarters may also check the run. Accurate data of daily catches and more information on the wind direction at the actual time and site of the elver runs are needed before further correlations can be made.

**5. Interaction of the Various Factors Affecting Elver Runs.**

Breaks in the migration dividing it into distinct runs may be one of two types:—

(1) Breaks of a week or so during which time conditions may vary but the run still does not restart. Absence of elvers, or their presence in the estuary only in quantities below the minimum necessary for a run, may account for this. This applies particularly to the end of the season. Alternatively the right conditions for running may be absent over the whole period. Low tides (as in 1938), or floods (as in 1943), may lead to such a period without a run.

(2) Breaks of a day or so are generally due to local quickly-acting factors, in combination or singly, such as heavy rain on the 17.—18. May 1942, and a gale or north wind, as on 22. April 1938, or a fall in temperature.

## IV. Discussion and Conclusions.

Water discharge appears to be the most important factor which influenced the migration of elvers in the River Bann in the years 1936—1943. Floods are important in two ways. Firstly, the number of elvers drawn into the River Bann estuary from the sea is proportional to the volume of fresh water discharged from the river in March and early April. This influences the season's total of elvers and the number of elvers available for any one run, since it is probable that the majority of these elvers migrate up into fresh water. Secondly, floods delay the starting date of the migration and this in turn influences the length of the season.

Thus short seasons often yield high totals of elvers, and *vice versa*, since both length of season and seasonal total are affected by March and April floods. The number of elvers trapped per running day is therefore higher in the short, high-total seasons. In short seasons, too, there are fewer runs than in long, low-total seasons. It is suggested that the continuity of migration may express the "urge" to migrate; if so, then it follows that the "urge" is greatest when the numbers of elvers migrating are highest. This mass incitement common to all migrating animals, the nature of which is still unknown, appears to stimulate the

elvers to overcome conditions which are adverse to the migration when fewer elvers are running. A comparison of the runs in the years 1940 and 1943 (see Figure 2) in relation to water discharge provides a good example of this. In the low-total year 1943, the breaks in the migration coincided with high discharges, although elvers could, as they did in 1940, continue to run in spite of higher discharges. Thus the threshold discharge above which the elvers will not run is not constant, and it appears that it is proportional to the numbers of elvers present in the estuary ready to migrate up the river. The tide, too, appears to have relatively less effect in high-total years, as in these years the elvers run equally from spring and neap tides whereas they run more often from spring tides in low-total years.

Floods, as in 1943, are not, however, common during the elver season as can be seen from Figure 2. Crowding of the elvers in the estuary may be a factor initiating and controlling the migration. It seems likely, for example, that non-availability of elvers may account for the breaks in 1939 and the latter part of 1938. The absence of stragglers also suggests that a minimum threshold number of elvers is necessary for a run to occur. This threshold will probably vary with other conditions.

The other factors considered, tide, temperature, and wind, do not seem to affect the run to any marked degree when considered separately. The checking effect of adverse wind, rainfall, or frost is evidently only brief, lasting a day or so, and since day-to-day correlations are not very reliable such breaks are not dealt with here in detail. The effect of a "hard winter" in delaying the start of the migration is due to the resulting spring floods, and is not an air temperature effect. No correlation was found between catches and wind direction but it is felt that these results were not very reliable as they were dependent on day-to-day totals.

The probable sequence of events may be summarized as follows:—

| | Extreme types of season | |
|---|---|---|
| | (1) | (2) |
| River discharge early in season | High | Low |
| Season's total catch | High | Low |
| Starting date of migration | Late | Early |
| Length of season | Short | Long |
| Number of running days | Same | Same |
| Catch per running day | High | Low |
| Number of runs in season | Few | Many |
| Effect of flood, tide, and weather on runs | Little effect, migration continuous. | Considerable effect, migration broken into distinct runs. |

It seems therefore that river discharge in the early season and the number of elvers in the estuary, itself influenced by river discharge, are master factors influencing the elver migration. Anything that can

be done, for example, by opening sluices and floodgates, to increase the flow of fresh water out to sea when the elvers are passing the estuary (in this case March and early April) should increase the season's elver catch.

## V. Summary.

1. All the elvers migrating up the River Bann are trapped at the top of the tide and transported up the river by lorry. Records of catches are kept and in this paper the numbers of elvers which migrated each year between 1936 and 1943 are examined in relation to conditions of tide, water discharge, and weather.

2. Water discharge appeared to be the most important factor influencing the migration. Years with floods in March and April gave the highest yield of elvers, probably owing to the fresh flood-water attracting large numbers of elvers in from the sea. These floods also delayed the starting date of the migration into fresh water, and led to a short elver season. It was found that the migration tended to be more or less continuous in these short, high-total seasons despite floods, tidal and weather conditions similar to those which checked the migration and divided it into distinct runs in the long, low-total seasons. The threshold water discharge which stops the migration is not constant and is proportional to the numbers of elvers present in the estuary as indicated by the season's total catch.

3. When the season's total is low the elvers run more often from spring tides, but when the total is high, elvers run from both spring and neap tides.

4. It was found that there was no relation between the "temperature advance" of the season (indicated by the date on which the mean weekly air temperature was first over 50°F. (10°C.) and the starting date of the migration. The average temperature for the four elver months, March to June, was very constant and showed that the total yield of elvers is not influenced by the temperature during the elver season.

5. The conditions of water discharge, tide, and weather checking the migration varied from year to year according to the number of elvers present. This suggested that the number and consequent "pressure" of elvers in the estuary may be an important factor controlling the migration.

6. It is concluded that river discharge early in the season and the number of elvers in the estuary, itself influenced by river discharge, are master factors influencing the migration of elvers into fresh water.

## VI. Acknowledgments.

I am deeply indebted to the late Major P. E. Shepherd, O. B. E., M. Inst. C. E., Director of Works for the Northern Ireland Government, and Mr. W. J. M. Menzies, F. R. S. E., Freshwater Fisheries Advisor to the Ministry of Finance, Northern Ireland, for supplying

the Freshwater Biological Association with the records of elver catches on which this paper is based. This paper was prepared while working with the Freshwater Biological Association under the directorship of Dr. E. B. Worthington and was the outcome of a visit by a colleague, Dr. W. E. Frost, to the River Bann. My sincere thanks go to Dr. Frost for sharing so freely her knowledge of the River Bann eel fishery and for her helpful interest throughout the preparation of this paper. In addition I would like to thank Mr. H. J. Buchanan-Wollaston for statistical advice and Mr. E. D. LeCren for much helpful criticism and advice.

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Oslo, 4th May 1951.

The Editor Journal du Conseil.

Dear Sir.

In my review of Dr. Jones's paper "Studies of the Scales of Young Salmon, *Salmo salar* L. (juv.) in relation to Growth, Migration and Spawning" in the *Journal du Conseil,* Vol. XVII, No. 1, a misunderstanding has arisen regarding scale samples collected from "the shoulder of the fish".

Dr. Jones has expressed this clearly in his letter to me of 24. April 1951, in which he writes as follows:—

"I read with interest your review of my paper called 'Studies of the Scales of Young Salmon', and was particularly interested in your remarks about the removal of scales from the 'shoulder'. I knew Dannevig's paper of course. Now Dannevig in his paper has got the wrong idea about what is meant by 'shoulder'. See page 80, para. 3 of his paper in the *Journal du Conseil.* He called the shoulder area F6 (his Figure, page 65). That is not what we call 'shoulder'. Our shoulder is F3, and in fact, to be more exact 'slightly in front and slightly below the front end of the dorsal fin'. All my scales have always been taken there, and I found that when many scale areas were sampled in salmon parr that this was the best spot (I've never published this work, which was done as a preliminary to my early scale work). I wonder if you could remedy this misunderstanding sometime in the *Journal.* I discussed the matter with Went when he came in to see me last week, and we both agreed that the misunderstanding was due entirely to the word 'shoulder'. In future I will always define this."

He adds:— "The first year in our 2-year-old smolt scales is quite well developed, and one with experience in scale reading would immediately become aware that there was something unusual about the scale if part or all of this year's was missing. One gets used to the look of the scales, and this is explained more scientifically in my paper where average counts of rings give some indication also.

I agree with you that in some of your more northerly, and older, smolts nothing would be easier than to overlook the first year rings."

It will appear that I have applied the Dannevig and Høst term "the shoulder of the fish" incorrectly in reviewing Dr. Jones's paper, which I highly regret.

I remain, Yours very sincerely,

*Sven Sømme.*

# Reviews.

**J. Grøntved.** "Phytoplankton Studies. I. *Nitzschia frigida* Grun., an Arctic-inner-Baltic Diatom found in Danish waters." Kgl. Dansk. Vidensk. Selsk., Biol. Medd., Bd. **18**, Nr. 12, 19 pp., 6 figs., 1 pl. København, 1950.

This account of the occurrence of *Nitzschia frigida* Grun., an Arctic and inner-Baltic ice-diatom, in Kattinge Bight, far from its usual haunts, raises several points of great interest.

The potential ecological importance of such "shadow forms", capable of intensive proliferation below ice 70 cm. thick, at a time when other phytoplankton organisms are almost absent, is well shown by the high supersaturation with oxygen of the very shallow layer of surface water immediately under the ice. This contrasted very strongly with the low oxygen content at greater depths, and also even in the surface layer at other stations worked near by, where the diatom concentrations were absent during the same brief period (early March, 1947). Incidentally, one would have liked to know whether any departure from the usual methods of estimating oxygen content were found necessary when such unusually high values as those given in Table 2, Sts. 3 and 4, were met with.

Several of the "Baltic-relict" diatom species are now known to extend beyond their normal Arctic distribution centre quite frequently. The author states that they "... may be regarded as having a bi-centric distribution, being stationary on the one hand in the Arctic seas, and on the other in the Baltic ... Where they have been observed outside these areas, they may be regarded as more or less chance occurrences, even though they may locally occur in great abundance where the ecological conditions have at times been favourable for their reproduction." This clear statement seems vastly more significant than speculations as to their possible value as indicators of former direct water communication between Arctic and Baltic. I personally can see no reasons why the inner-Baltic should not be re-seeded with Arctic neritic ice-diatoms — so tough and tolerant of wide variations in environmental conditions other than temperature (*vide* the salinity values cited here) — in most years. The distance is not great as sea-birds fly.

The photomicrographs of individual frustules are good, and that showing the characteristically irregular branching colony exceptionally interesting. A precisely similar colonial habit is typical of a very closely similar Antarctic ice-diatom described by M. Peragallo as *Thalassionema gelida*, but which I, for one, first took to be *Nitzschia frigida* when meeting it "in the field". Some other members of the ice-flora tend to form like colonies — perhaps

owing to proliferation around slowly forming ice-crystals. The taxonomic definitions of some pennate diatom genera are so confusing and obscure that further work on any of them is valuable, provided that good illustrations and series of measurements are included, as in the paper under review. It is just possible that *Thalassionema gelida* M. Peragallo (lacking the marginal spicules required by Hustedt's re-definition of the genus) may yet prove to be synonymous with *Nitzschia frigida* Grun. Their structural similarity as observed by normal methods of microscopy is very close, but the forms ascribed to *Thalassionema* tend to be somewhat larger.

Although there are important differences in the conditions under which ice-floras develop in the two hemispheres, no one knowing the southern form could fail to be struck by the close analogy, in habitat and in habit, between these diatoms from the opposite ends of the earth, after reading this paper.

*T. J. H.*

**Rudolf Kändler.** "Jahreszeitliches Vorkommen und unperiodisches Auftreten von Fischbrut, Medusen, und Dekapoden-Larven im Fehmarnbelt in den Jahren 1934—1943." Ber. Deutsch. wiss. Komm. Meeresf., N. F., **12**, 1, S. 49—85, Abb. 1—6. Stuttgart, 1950.

Using material from vertical hauls with the Hensen net from the "Fehmarnbelt" lightship in the western Baltic, 3 times a month in 1934—1943, the author deals with the occurrence of pelagic eggs and larvae of fishes and of certain bigger plankton animals, and compares their varying frequency with fluctuations in hydrographic conditions.

Eggs of cod, sprat, flounder, and dab are the most common fish eggs; the number of eggs of the plaice nowadays is far less than what was the case years ago. It is of interest to note that eggs of the mackerel occur regularly.

The main spawning periods of cod, plaice, and flounder fall later in severe than in mild winters, and the same is to some degree the case also for the dab.

The range of the yearly variations in the number of eggs is dealt with. In 1935—39 the number varied only little; 1937 yielded the biggest catches, but only about twice as large as the other years. During the severe ice-winters 1940/41 and 1941/42 the egg number was considerably below the mean for the years 1935—39. For cod, plaice, flounder, and sprat the number of larvae found is 2—6 for 100 eggs; for the dab the number of larvae is far bigger, 6—21, and in one year 70 for 100 eggs. The author is of the opinion that the majority of the eggs found are spawned in the western Baltic. The proportionately rich occurrence of larvae of dab is, however, caused by an inflow of such larvae from the north.

Kändler has observed in the Fehmarnbelt, as Kramp did (1913) in the Langelandsbelt, that the number of eggs (of cod and others) was higher the higher the salinity, but whereas Kramp drew the conclusion therefrom that eggs were carried to the area by the salt-water current from the north, Kändler is of the opinion that the rich occurrence of eggs in association with salt water is caused by the fact that the salt water induces the fish to spawn. To the reviewer it appears that a determination of the stage of development of the eggs could have served to solve the question.

Of the planktonic invertebrates especially the medusae and the decapod larvae are dealt with. It is shown that the planktonic invertebrates indigenous to the area exhibit yearly fluctuations in number corresponding to the fluctuations of the number of eggs and larvae of the fish of the area. In addition, a number of plankton organisms ("indicator species" for Kattegat water) from

outside occur in the material, indicating strong currents from the north. These guests are *Purena, Steenstrupia, Eutonina, Euphysa tentaculata, Bougainvillia, Aglantha, Mesopodopsis, Tomopteris,* and larvae of *Pandalus, Hyas,* and *Portunus.* It is, however, quite possible that the larvae of *Hyas* should not be regarded as guests; adult species of this crab have been caught fairly often during Danish experimental fishing in the western Baltic. As *Pandalus montagui* is rather common in the Belts, the occurrence of larvae of *Pandalus* cannot be regarded as a proof of an inflow of water from the Kattegat.

It is of great interest that the author shows that the current conditions for an influx from the north are far better during the summer than in spring and that the planktonic guests from the north therefore are those occurring during summer and autumn and not in spring; this is interesting, but discouraging, for it is just the larvae of the main food fishes which occur in spring; it explains why we so very rarely have an influx of importance to the fishery, such as the influx of haddock larvae in 1923.

*Erik M. Poulsen.*

**Sigurd Johnsen.** "Studies on Variation in Fish in North-European Waters. I. Variation in Size." Bergens Mus. Årb. 1944. Naturv. rekke, nr. 4, 129 pp., 80 figs., 1 map. Bergen, 1945.

The paper deals with the question of variations in size of certain species of fish from north European waters and with factors governing such variations. The material was collected mainly in Norwegian coastal waters, but has been supplemented with material from other countries. The species dealt with are either purely coastal fishes or more oceanic ones:— *Spinachia vulgaris, Gobius flavescens, Myctophum glaciale, Hippoglossoides platessoides, Pleuronectes platessa,* and *Lycodes vahli.*

The two coastal species *Spinachia vulgaris* and *Gobius flavescens,* which have a short life-cycle and do not travel far, are dealt with most thoroughly.

The author shows that *Sp. vulgaris* reaches its largest size in the southern part of its area of distribution (English Channel, southern North Sea, and the Danish waters), and he states that it has a giant form up to 17 cm. at Helgoland and a dwarf form (only up to 12 cm.) in northern Norway. In both areas it lives only one year.

As to *Gobius flavescens* the author finds that it attains a bigger size in the northern part of its habitat (western Norway, up to 65 mm.) than in the southern part (Danish waters, up to 45 mm.). In connexion with this the species reaches two years of age in the northern area against only one in the southern area.

*Myctophum glaciale* grows in northern waters to a length of 95 mm. against only 50 mm. in the Mediterranean Sea. In the northern seas it dies before reaching an age of 3 years, in the Mediterranean before it is 2 years old.

For the various races of *Lycodes vahli* the author states that the races from the arctic areas attain a bigger size than those from more southern waters. Unfortunately the age of the individuals investigated is not known. The males become larger than the females.

Also *Hippoglossoides platessoides* grows larger in northern waters (Barents Sea) than in southern (Danish waters) and it attains maturity at an older age in northern than in southern waters.

For the plaice it is stated that it reaches a bigger size in northern than in southern waters, and comparing Iceland and the western Baltic the author finds that the growth after the age of 2 years is less in the western Baltic than

at Iceland. It is somewhat astonishing that the author only uses the older literature; for the western Baltic, A. C. Johansen, 1912; the North Sea, Otterstrom, 1914; and Iceland, Sæmundsson, 1926. If the author had used the vast new literature for all these areas, he would have got a far larger material and would have seen that in dealing with the growth of heavily fished food fishes, one must consider the intensity of fishing, and that growth is not a constant factor of a fish population, but varies, changing from year to year or from period to period in accordance with changes in the size of the stock.

In a chapter entitled "discussion" the author gives a very interesting survey of the influence of hydrographical conditions on the growth, and he sums up in the following way:— variations in temperature may be expected to be followed by variations in the size of the fishes that use the area in question for their feeding grounds. These variations may be caused by differences in (1) the age at first maturity, (2) the growth-rate (amount of food), and (3) the duration of the yearly growth-period. I am afraid that fishery biologists sometimes have not paid sufficient attention to point 3.

In the last chapter the question of the maintenance of the species in the light of varying egg production is discussed.

For the fishery biologists reading the paper it is somewhat annoying that when speaking about age the author uses the term "group" in another sense than that normally used, "and a group II ... it is about one year and a half" (p. 42), "individuals ... beginning their second year (group II)" (p. 44).

The paper deals with questions of special and great interest to fishery biology, and the author looks upon and deals with the question in a new and fresh way, thereby adding considerably to the value of the paper.

For the readers it would have been a great help if the author had given a summary of the paper, especially as the results are hardly stated even at the close of the chapters but are to be found all through the text. Not all who wish to use this valuable paper can afford the time to read it line by line.

*Erik M. Poulsen.*

**W. F. Thompson.** "The Effect of Fishing on Stocks of Halibut in the Pacific." 60 pp., 12 figs. University of Washington Press, Seattle, 1950.

**Anon.** "Regulation and Investigation of the Pacific Halibut Fishery in 1947 and 1948." Rep. Internat. Fish. Comm., Nos. 13 + 14. Seattle, 1948 and 1949.

The first two annual reports of the International Fisheries Commission offer a useful historical introduction to Dr. Thompson's paper. They are to be welcomed as providing a medium for the regular publication of statistics relating to the regulation of the Pacific halibut fishery, around which has centred so much controversy during recent years.

Dr. Thompson sets out to answer the criticisms that limitation of the catch of halibut has been greater than can be justified, that many of the apparently beneficial results of regulation are in reality caused by natural fluctuations, and that in any case these fluctuations outweigh in effect the changes in the population size caused by the fishery.

It is the reviewer's opinion that he succeeds in establishing that the fishery has a considerable effect on the stocks of halibut, and it cannot be denied

that although natural fluctuations may have exaggerated the apparent effects of shortening the fishing season — for that is the way in which the imposition of a catch quota has reduced the fishing mortality in this population — nevertheless, the general trends of catch and catch per unit effort over the period 1930—1946 (Thompson's Figs. 1 & 2) are such as would be expected if the effect of regulation had been to bring the average catch down to a value less than the average yearly increment due to growth and recruitment. In the author's words, "This (has) come as naturally and inevitably ... as the accumulation of water behind a dam across a river." He finds himself "no more capable of postulating a vague cycle or unknown natural cause for the change in the stocks of halibut than I can regard the action of a dam in forming a lake or pond as a mysterious thing," and can see "that the river, dammed or not, is subject to changes in volume when it rains, and that the spill over the dam varies accordingly."

It is unfortunate that in introducing the concept of *the normal yield* Dr. Thompson does not make it clear at the outset that the validity of using values derived from the average yearly catches in pre-regulation and post-regulation phases of the fishery depends upon the fact that the yield from the Pacific halibut population, in common with that from many other demersal fisheries including the North Sea plaice, is remarkably constant for quite a wide range of fishing effort. It is pointed out that the "normal catch per set", that is, the average catch over the period 1926—1933 divided by the number of sets of gear in any one year, is inversely proportional to the number of sets. When the *actual* catch per set ($c$) is then plotted against the number of sets ($f$) the points are seen to lie close to the reciprocal curve and this closeness is then measured by calculating the coefficient of correlation between log $f$ and log $c$. This is found to be $-0{\cdot}96 \pm 0{\cdot}02$ for the southern grounds, and $-0{\cdot}90 \pm 0{\cdot}04$ for the western grounds, and it is concluded that "this is far beyond any probable coincidence between the economic changes in the fishery and natural fluctuation", and it is claimed that this "should set at rest any doubt as to the dominant part played by the fishery in determining the magnitude of the stock of fish." In fact the number of sets and the catch per set have not been estimated independently and the high values of the correlation coefficients that were found have no special significance; they do not demonstrate that fishing has played the *dominant* part in determining the size of the stocks.

A further difficulty in accepting as satisfactory this analysis of the relationship between catch per set and number of sets, arises because the figures for number of sets of gear are obtained from the ratio of total catch to catch per set, and the total catch has been in fact held more or less constant from year to year. The result is that any variations in the availability of fish from year to year due to "natural causes", appear in the statistics as variations (in the opposite direction) in the number of sets, and not in the catch per set. This does not, however, in itself invalidate the conclusions at which Thompson arrives after consideration of the deviations of the observed points from the reciprocal curve.

The critical point of the discussion arises when it is pointed out that if the intersections of co-ordinates representing $f$ and $c$ are connected by lines with arrows to show their time sequence, then variation from the reciprocal line ("normal" catch per set plotted against number of sets) is not random. In general the points relating to the earlier years, when the catch per set was decreasing and number of sets increasing, lie above the reciprocal line, and when, in later years, the catch per set was increasing and the number of sets

decreasing, the points lie below it. It is clear that here the fish stock is "responding" to changes in the fishing intensity, but as the latter does not remain stable, equilibrium is not reached, and it is not until after 1936 in the case of the western grounds and 1940 for the southern grounds, when the number of gear sets remained fairly constant, that the stocks accumulated sufficiently to give a yield equal to, or even greater than, the "normal". Now if the amount of fishing is reduced there must come a point when the total catch is also reduced, and indeed with very low fishing intensities the total catch would be expected to be roughly proportional to the number of sets of gear. Clearly, under these conditions a reciprocal relationship between the number of sets of gear and the *equilibrium* catch per set must break down, but it might be expected to hold good when fishing is intense. In particular if such a fishery is based upon a population either in which the natural mortality is high compared with the growth-rate of the fish, or where the food is in limited supply, and consequently the growth-rate varies with the population density, the average total catch might well be largely independent of the number of sets of gear in use. In these cases the "best fishing" is determined as much by economic considerations as by the biological characteristics of the fish, and the optimum could only be defined arbitrarily as the minimum fishing intensity which would give a sustained annual yield near to the greatest possible catch. No evidence has been presented so far by the critics of the Pacific halibut regulations that the fishing on this species has been reduced to a value below the optimum. This is particularly remarkable in view of the fact that the original methods used by Thompson and Herrington to obtain the fishing mortality from tagging experiments can give considerable over-estimates of this quantity, and it might have been expected that because of this there was a danger of over-regulation. In the case of the halibut it has turned out that the decision to use catch quotas and not direct control of fishing intensity has been a safeguard against this.

Dr. Thompson's paper will no doubt provoke a great deal of further discussion, but he has shown that the International Fisheries Commission were in general correct in their regulative action, and further, that the actual limit set, based upon the "normal yield", was a very good guess at the optimum necessary to achieve truly rational exploitation of the pacific halibut stock.

*S. J. H.*

**Kenneth D. Carlander.** "Handbook of Freshwater Fishery Biology." Wm. C. Brown Company. 281 pp., 5 charts. Dubuque, Iowa, 1950.

In the preface the author calls the present book a source for quick reference to data on freshwater fishes. This description holds good, however, with certain limitations only. In the first place the book deals chiefly with American freshwater fish: only 12 out of about 160 species and forms described are common both to the Old and the New World. Secondly the anadromous species are not treated in general; for instance, information on the Pacific salmon, *Oncorhynchus spp.*, will be looked for in vain: the Atlantic salmon, however, forms an exception. I shall revert to this later.

The main section of the book consists of series of data, in tabular form on the growth, length, weight, various length relationships, etc. of the species under consideration. Within each species the information is arranged in the following order:—

1. Conversion factors for standard to fork length
2. Conversion factors for standard to total length

3. Standard length-weight relationship
4. Fork length-weight relationship
5. Total length-weight relationship
6. Condition indices
7. Size at capture, by age-groups
8. Calculated standard lengths at each annulus
9. Calculated fork lengths at each annulus
10. Calculated total lengths at each annulus
11. Egg counts.

All these data are accompanied by a note about the source of the information thus providing a valuable list of literature of no less than 41 pages.

Let us take a species common to the western and eastern area, the Atlantic salmon, to show the information which can be gained from the tables. A discussion of the various conversion factors is followed by the mean weight in ounces and number per pound of fry together with some examples of condition coefficient (K and C).

In this connexion it is worth mentioning that standard length is always recorded in millimetres, and fork and total length in inches and tenths of an inch; this certainly does not make for convenience in using the tables, even if a table (p. 228/9) for conversion is appended.

Next follow surveys of the size at capture, by age-groups, and the various calculated lengths. This section, however, in which millimetres, inches, grammes, ounces, and pounds are used together in a most confusing way, does not impress a European worker, nor does the information given therein. The fact that the island of Bornholm is moved from its original situation in the Baltic to Norway, may perhaps be explained by its great distance from America. A more serious defect is the fact that the figures for calculated standard lengths during life in fresh water given for Norwegian salmon, according to the source mentioned, do not represent standard lengths but total lengths, and that they are based upon 1 (one) fish from Bornholm and 1 (one) from a small lake near Bygland, Norway, or a landlocked salmon. In this connexion it may also be mentioned that neither the "Blege" from the Bygglandsfjord nor the landlocked salmon from the Vänern are referred to in the consideration of "*Salmo salar sebago*, including other landlocked forms", even though both forms are described in literature, and literature at that which should not present linguistic difficulties to an American.

The lone Bornholm salmon is also presented in the section "Size at Capture" illustrating the fork length of Norwegian salmon, and the total length given in the original in cm. is converted into inches. We then meet again the same fish as sole representative of Norway under "calculated fork length at each year of sea life". In all justice, however, it must be admitted that a real Norwegian salmon is indeed mentioned, i.e., a single fish, the "mean weight" of which is taken from an English book on salmon. Unfortunately, the author does not seem to have heard of such prominent salmon experts as Knut Dahl and Huitfeldt-Kaas; in their works he might otherwise have found, in his own language, all the necessary information.

The facts criticised above — or perhaps others — may possibly have inspired the author to mention in the preface that "not all the data in the tables are of equal value", and indeed he is right in saying that the book cannot serve "as a substitute for reference to the original papers". It is further to be hoped — the reviewer is unable to decide at the moment whether it is actually so — that the data given for the American fish species are more

correct and better substantiated. In that case the book will have its value for those, for whom it is primarily intended, the American conservationists and biologists.

*K. L.*

**J. W. Jones.** "Salmon Studies." Min. Agric. and Fish., Fish. Invest., Ser. I, Vol. **5**, No. 2, pp. 1—23. London, 1950.

The salmon of only a few rivers in England and Wales have been studied scientifically and therefore Dr. Jones's paper "Salmon Studies", which is concerned with the Rivers Avon, Itchen and Cumberland Derwent, is very welcome. As regards the Avon and Itchen the work was carried out at the Southern Station (Avon Biological Research) of the Freshwater Biological Association in 1939 and 1940 before that station closed down on account of the war. Jones analyses collectively material from adult salmon collected by himself in 1939 and 1940 and by other workers in the years 1934, 1936, and 1937. He shows that in both rivers the proportion of 1-year smolts is high (88 %—92 %), higher in fact than any other British river and one might add, Irish river too. The bulk of the fish were spring fish, the runs of large spring fish (3 sea winters) being dominant with a peak in March. Small spring fish were next in importance forming about 16 % of the total. About 5 % of the fish examined were very large spring fish (4 sea winters), a class which may be regarded as somewhat rare in British and Irish waters. The condition of the fish was average to good (0·98—1·14 on Menzies' scale).

In 1940, 395 salmon smolts were caught in the Avon and examined. Scale reading confirmed that the bulk (88·5 %) were yearlings with an average length of 15·5 cm. Other smolts taken in the same year in the Avon and Piddle (Dorset) included at least one mature male yearling smolt.

The second portion of the paper deals with the Cumberland Derwent and is based on 1,080 readable sets of scales taken in the years 1946 to 1949. Only 13 % of the fish were "spring fish" of which two-thirds had spent 2 years or thereabouts feeding in the sea. A large proportion of the scales were eroded. The proportion of 2-year smolts ranged from 91·6 % to 97 % in the different years, with the 3-year smolts always more important than the yearling smolts. Condition in all the fish was good.

Jones's investigation again raises an interesting point. From scale reading the fish were classified into "spring fish", with a close band of rings, and "summer fish", with widely spaced rings on the margins of the scales. In many Irish rivers we know that late-running grilse have a close band of rings on the scale margin and therefore would, if scale reading were the only criterion, be considered as "spring fish". It seems that in Jones's tables "spring fish" may be divided into two types, i.e., those true spring fish which have ceased to feed in the winter prior to the return to the river, and late autumn fish which because the growth-rate has slowed down show on the margins of the scale a close band of rings, which cannot, in most cases, be distinguished from the true winter band. There is, therefore, a need to investigate this matter further and the Cumberland Derwent would seem to offer the necessary conditions for study. What is needed is a scientist resident on the river for a season to take scale samples and examine, if possible internally, every fish. In Ireland we also hope to examine this problem in the near future as we have found a small river which seems to offer the right conditions to investigate these late (early?) running fish.

*A. E. J. W.*

# Current Bibliography.

Prepared by the Editor with the Assistance of Mr. A. C. Simpson.

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NOTE. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given, but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

Subscribers and those on the distribution list will receive regularly upon application to the General Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

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